G.E.C. Journal

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CONTENTS

PAGE

FRONTISPIECE – – – – – – – – – 80

ELECTRICAL AND MECHANICAL EQUIPMENT AT THE EBBW VALE STEELWORKS OF RICHARD THOMAS & CO., LTD. – – 81
By H. Nielsen and S. A. G. Emms

THE APPLICATIONS OF ELECTRIC DISCHARGE LAMPS TO PHOTOGRAPHIC PROCESSES – – – – – – 93
By H. J. A. Turner

THE NEW SOUND MEASUREMENT BUILDING AT WITTON – 106
By H. Jacoby

INSTRUMENTS INCORPORATING THERMIONIC VALVES, AND THEIR CHARACTERISTICS – – – – – – 112
By E. G. James, G. R. Polgreen and G. W. Warren

RECENT PROGRESS IN ELECTRICITY METER CONSTRUCTION – 124
By S. James

THE G.E.C. TWELVE-CHANNEL CARRIER SYSTEM FOR TELEPHONE CABLE CIRCUITS – – – – – – 133
By C. Riley

HIGH-FREQUENCY ELECTRIC MELTING FURNACES. AN INSTALLATION AT BROCKHOUSE CASTINGS, LTD., WEDNESFIELD, WOLVERHAMPTON – – – – – – 142
By S. Evans

A NOTE ON THE OPERATION OF THE PERIODICALLY IGNITED MERCURY-POOL RECTIFIER – – – – – – 150
By D. G. Prinz

TECHNICAL LITERATURE – – – – – – – 152

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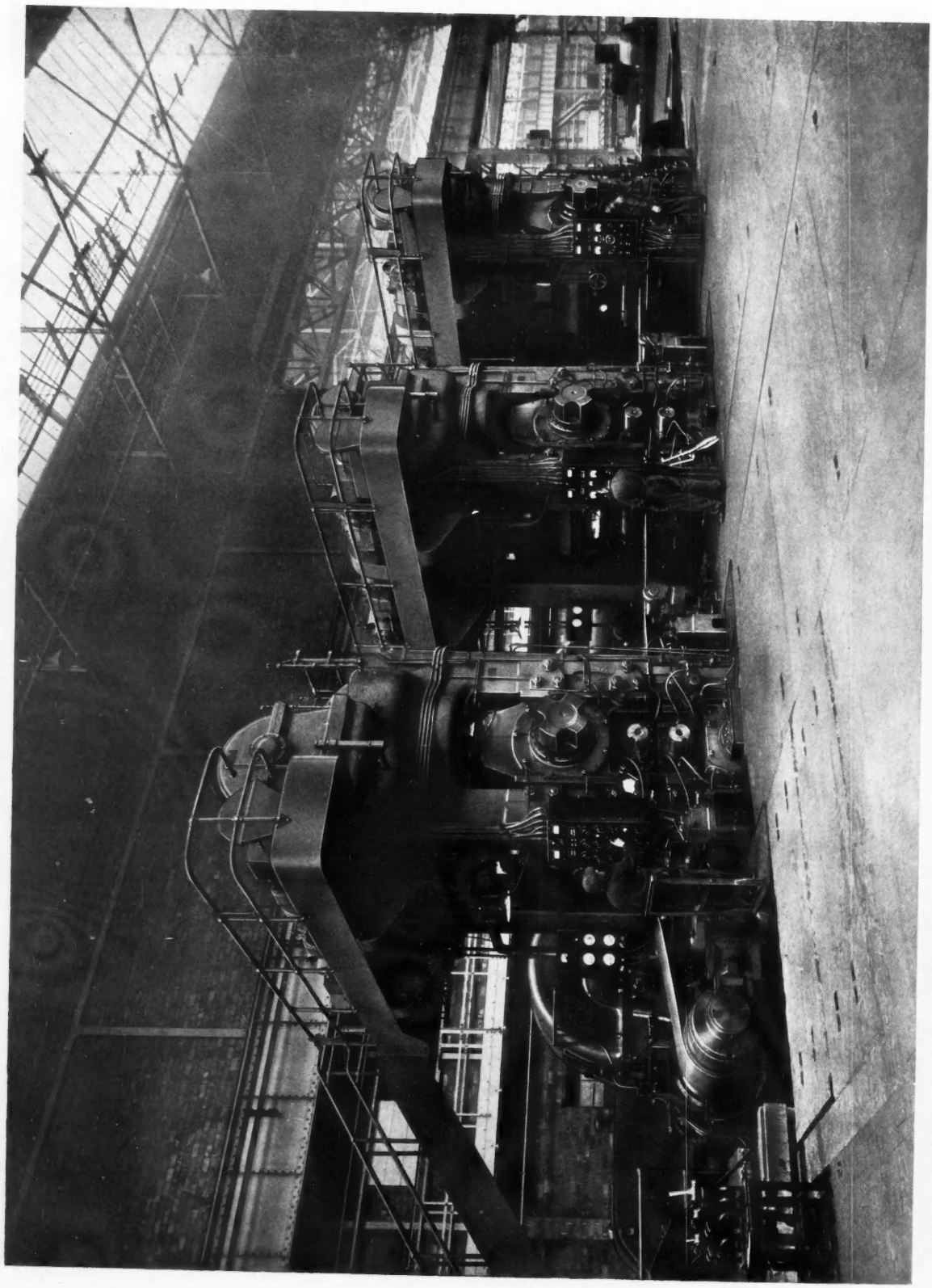


THE 3-STAND TANDEM SHEET MILL IN THE COLD MILL OF THE EBBW VALE STEELWORKS OF RICHARD THOMAS & CO., LTD.
The three stands of this mill are each driven by a 1,500 h.p. 500 volt. 350/700 r.p.m. D.C. motor under Ward-Leonard control. The speed of the mill is adjusted by the control cabinets at the side of each stand.

G.E.C. Journal

VOL. X. MAY, 1939. No. 2.

Electrical and Mechanical Equipment for the Ebbw Vale Steelworks of Richard Thomas & Co., Ltd.

By H. NIELSEN, B.Sc., A.M.I.E.E. and S. A. G. EMMS, B.Sc.,
Witton Engineering Works.

IN 1935, Richard Thomas & Co., Ltd., one of the most powerful industrial combines in Great Britain, purchased the works and subsidiary undertakings of the Ebbw Vale Iron & Steel & Coal Co., Ltd., and started the gigantic task of reorganisation and reconstruction, which in 1938 culminated in one of the largest steelworks in Great Britain embodying the first plant of its kind in this country for the production of steel in strip form.

The site purchased at Ebbw Vale is 2½ miles long and ¾ mile wide. Some of the reasons for the choice of this particular site were that adequate supplies of coal and limestone are adjacent and there is a good water supply. Further, the site is not only covered by a network of railway track which is directly connected to two main lines, but is also not far from seaports on the Bristol Channel. Plenty of labour is available in the surrounding "distressed" area and the site itself is remote from attack in time of war.

Fig. 1.—View along the hot mill at the Ebbw Vale Steelworks of Richard Thomas & Co., Ltd., showing in the foreground the blooming mill and slab shear.

The three stands of this mill are each driven by a 1,500 h.p. 500 volt. 350/700 r.p.m. D.C. motor under Ward-Leonard control. The speed of the mill is adjusted by the control cabinets at the side of each stand.

At the start of the reorganisation practically the whole of the old works were pulled down, with the exception of the power station, a coke oven battery and by-product works and other small departments. In their place new buildings have been erected containing the most up-to-date plant capable of

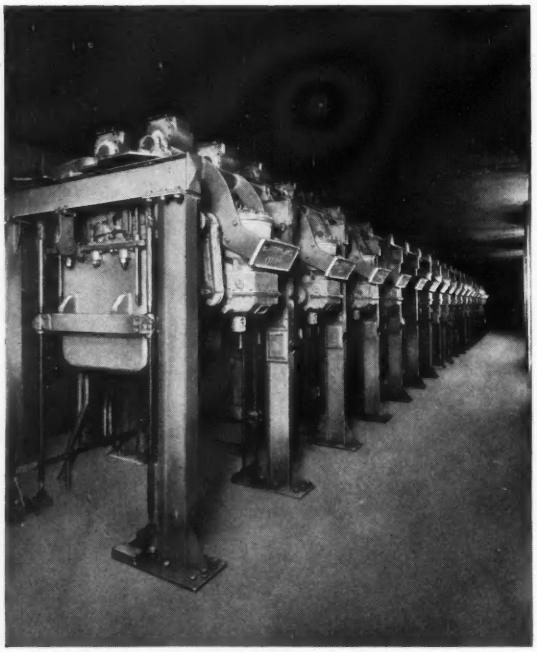


Fig. 2.—17-unit 11,000 volt, 550,000 kVA metalclad switchboard installed in the hot mill, controlling the whole of the electrical supply to this mill. A similar switchboard controls the supply to the cold mill.

manufacturing 600,000 tons per annum of finished sheet steel direct from the essential raw materials. There is little doubt that the completion of this vast new enterprise with its highly mechanised and closely controlled processes of manufacture, has done much to place Great Britain on a competitive level with any other country in the export market for sheets and tinplates.

The method of production adopted is based on the latest American practice which employs the electrical drive almost exclusively to obtain the high degree of quality required.

It is not possible in this article to deal with all the processes involved at Ebbw Vale in the production of steel from raw materials and its subsequent treatment, and the following description is, therefore, confined to the hot and cold continuous strip rolling mills with special reference to the electrical and mechanical plant which the G.E.C. has installed.

The size of the contract, which is one of the largest ever placed in this country for this class of equipment, may be gauged from the fact that over 2,000 tons of mechanical gear together with electric motors totalling over 16,000 h.p. in capacity, control gear, switchboards and transformers, are of the Company's manufacture.

The mechanical gear was manufactured to the designs of the United Engineering & Foundry Co. of America, by the Fraser & Chalmers Engineering Works of the G.E.C., while the electrical equipment was designed and manufactured at the Witton Engineering Works.

ELECTRICAL POWER SUPPLY AND MAIN SWITCHGEAR.

The supply to both the hot and cold rolling mills is obtained from a 132/11 kV grid substation installed close to the works. Two feeders at the lower voltage are taken to the hot mill and two similar feeders to the cold mill. Both feeders at the hot mill terminate at a 17 unit metalclad board and, in the cold mill, at an 11 unit board of the same type and manufacture. The units on both switchboards are provided with oil circuit breakers having a rupturing capacity of 500,000 kVA at 11,000 volts. The whole of the

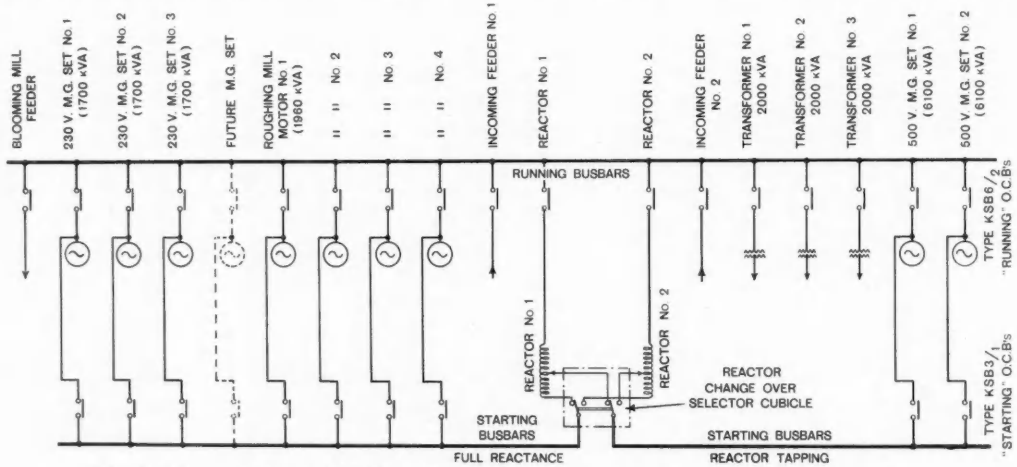

BLOOMING MILL FEEDER
230 V. M.G. SET No. 1 (1700 kVA)
230 V. M.G. SET No. 2 (1700 kVA)
230 V. M.G. SET No. 3 (1700 kVA)
FUTURE M.G. SET
ROUGHING MILL MOTOR No. 1 (1980 kVA)
" No. 2
" No. 3
" No. 4
INCOMING FEEDER No. 1
REACTOR No. 1
REACTOR No. 2
INCOMING FEEDER No. 2
TRANSFORMER No. 1 2000 kVA
TRANSFORMER No. 2 2000 kVA
TRANSFORMER No. 3 2000 kVA
500 V. M.G. SET No. 1 (6100 kVA)
500 V. M.G. SET No. 2 (6100 kVA)
RUNNING BUSBARS
TYPE KSB6/2 "RUNNING" O.C.B's
REACTOR No. 1
REACTOR No. 2
REACTOR CHANGE OVER SELECTOR CUBICLE
TYPE KSB3/1 "STARTING" O.C.B's
STARTING BUSBARS
FULL REACTANCE
STARTING BUSBARS
REACTOR TAPPING

Fig. 3.—Key diagram of 11,000 volt, 500,000 kVA metalclad switchgear in hot mill.

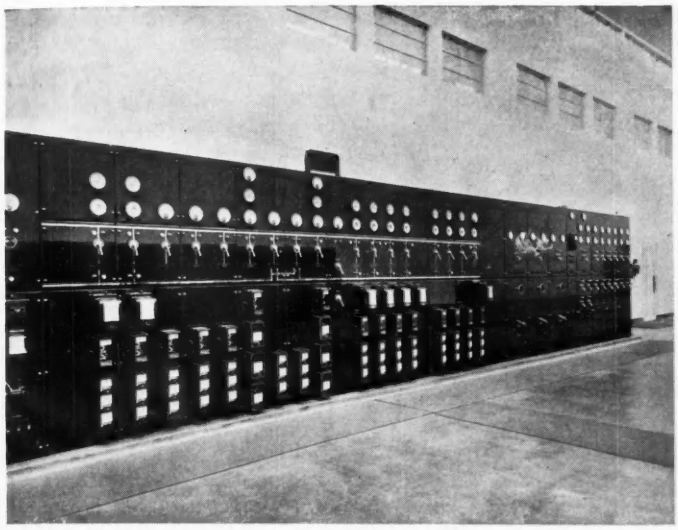


Fig. 4.—Remote control switchboard in motor room of hot mill, controlling metalclad switchboard shown in Fig. 2.

electrical supply to the hot and cold mills is controlled by these two switchboards, one of which is shown in fig. 2.

It will be seen from the diagram, fig. 3, that some of the outgoing feeders from the switchboard supply power direct to large synchronous motors but as these motors are started with a reactance in circuit, the switchboard is provided with a duplicate set of busbars, one set being connected to the synchronous motor through a common reactance by a "starting" circuit breaker, and the other set being connected direct to the motor by a large "running" circuit breaker. The breakers, both large and small, are solenoid operated and interlocks are provided which prevent any two motors being started up simultaneously or the starting circuit breaker of a motor remaining in circuit after the running breaker is closed. The starting circuit breakers are placed at the back of their respective running breakers and the general design of the switchboard follows the Company's standard practice in this class of equipment.

The switchboards in the hot and cold mills are operated from remote control boards situated in the motor room of each mill. Each remote control board is fitted with the usual metering equipment and a mimic diagram so that the operator can see at a glance the position of the various switches under his control. The control board in the motor room of the hot mill is shown in fig. 4.

For the low tension A.C. supply for both the hot and cold mills a total of five 2000 kVA, 11000/440 volt transformers have been supplied, three for the hot mill and two for the cold mill.

THE CONTINUOUS HOT-STRIP MILL.

The steelworks lie to the south of the site, conveniently near to the blast furnaces, and consist of three open-hearth furnaces, three Bessemer converters and one mixer.

This combination enables the company to produce direct open-hearth and direct Bessemer or Duplex steel for various products. From the steelworks the ingots are taken to eight circular soaking pits at the south end of the hot rolling mill (a building 2260ft. long and 235ft. wide) where they are brought up to the required temperature for the blooming mill. In this mill, which is capable of dealing with 750,000 tons of ingots per annum, the ingots are reduced to slabs of any desired size up to 52ins. max. width. The slabs are conveyed from the mill over electrically driven rollers to the slab shear where the ends are cropped square and the slab is sheared into suitable lengths for further treatment. The finished slabs are then conveyed either to the slab storage buildings via a chain conveyor (fig. 5) where the slabs are cooled and conditioned, or charged hot to the entry side of the slab re-heating furnaces. The heated

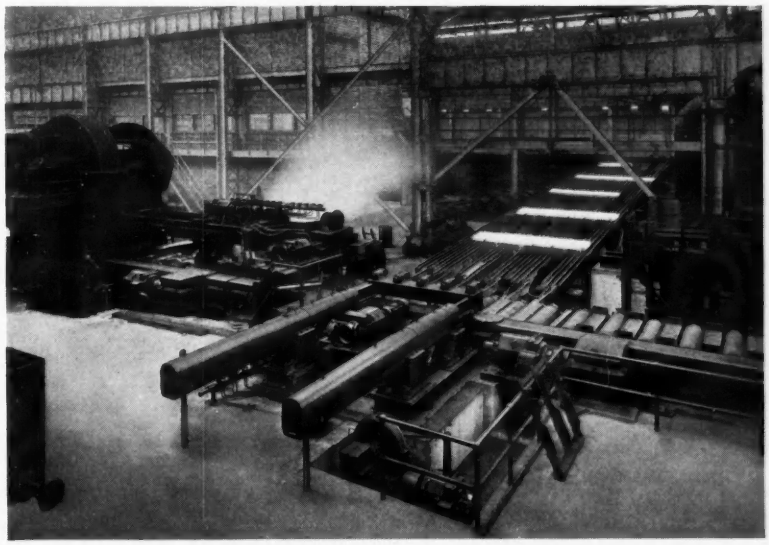


Fig. 5.—Hot slabs from the shear (on the left) being taken by conveyor to the slab re-heating furnace. The slab pusher in the foreground is driven by a 25 h.p. 650 r.p.m. motor. Other motors on this equipment are a 25 h.p. shear gauge lift motor, a 15 h.p. shear gauge traveller motor and a 7½ h.p. disappearing stop motor. All motors are of the D.C. steelworks type.

slabs are discharged on live roller tables which take them to the continuous hot strip mill which consists of eleven stands of rolls arranged in tandem. The first stand is a two-high roughing scale breaker in which primary scale formed on the slab in the re-heating furnaces is loosened. Water is sprayed at high pressure on the top and bottom of the slab and cleans the loosened scale from the slab as it is delivered from the stand. Between this mill and the first roughing mill a horizontal slab reducer is provided, in which the slab is squeezed to accurate width with straight and parallel edges. From the reducer the slab is conveyed over driven roller tables through three two-high roughing stands and one four-high roughing stand. High-pressure water sprays are placed at each mill to remove secondary scale. Vertical edging rolls are provided at the entrance to the second and fourth roughing mills.

Between the roughing and finishing mills the strip is conveyed over an air-cooling table, where the temperature is automatically recorded and regulated before the finishing rolling to exact thickness begins. At the delivery end of the air table a two-high finishing scale breaker loosens secondary scale, which is cleaned away by high-pressure water sprays.

From the scale-breaker the strip enters the finishing train of mills, figs. 6 and 7. There are five four-high mills in tandem in the finishing train and strip is rolled continuously through all five stands. Strip is delivered from the finishing mills at speeds up to 1,850ft. per minute, and single strips may be as long as 1,700ft. Widths from 12in. to 50in. and thicknesses up to 0·375in. may be rolled.

On delivery from the rolling mills the strip is

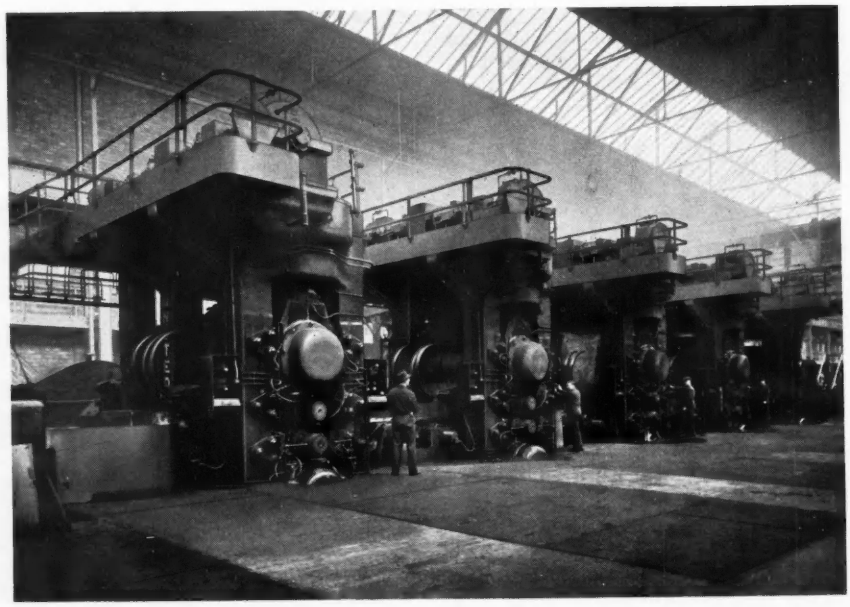


Fig. 6.—The 5-stand hot strip finishing mill. The ten screw-down motors on this mill are all rated at 25 h.p. 850/1300 r.p.m. and are of the D.C. steelworks type.

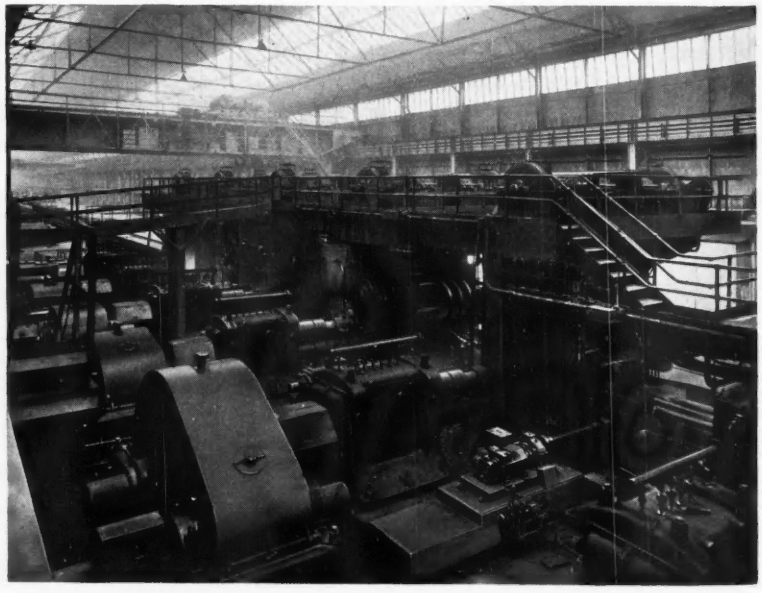
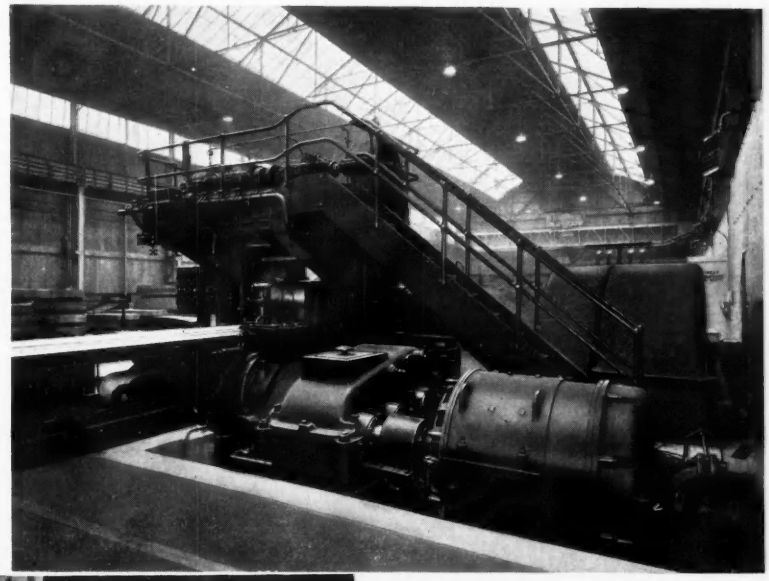


Fig. 7.—Another view of the 5-stand finishing mill.

either coiled or sheared into lengths of from 8ft. to 32ft. by an automatic flying shear located directly beyond the last finishing mill. The sheared lengths are conveyed over an individually motor-driven roller table to an automatic piler, and the stacks of sheets are transferred from the piler by chain conveyor. Strips to be coiled are conveyed over the same run-out table to either one of two automatic down-coilers. The coilers are so arranged that either one is operating while a coil is being removed from the other. The coils of strip are discharged into upenders which place them on chain conveyors. The coils are then either removed by overhead crane to storage in the hot mill coil storage building or continuously transported to the cold mill.



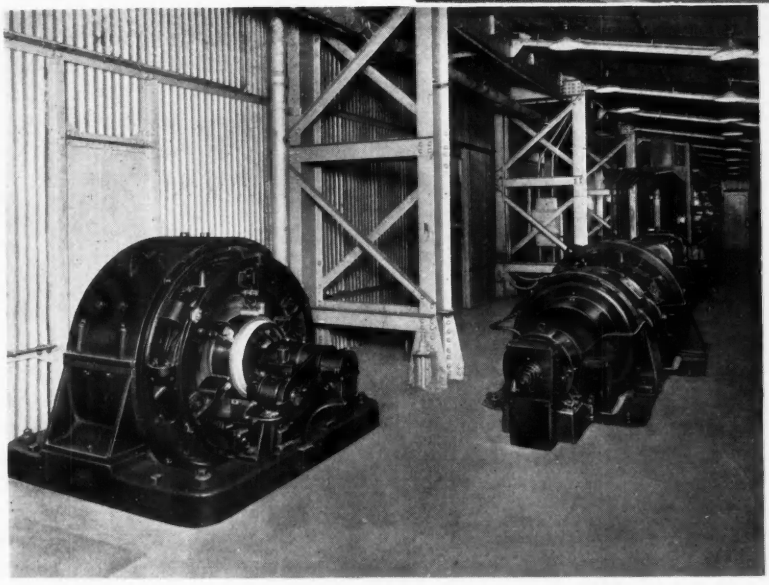


Fig. 9.—View in motor room of skin pass mill shown in fig. 8. On the left is the 300 h.p. 400/800 r.p.m. D.C. motor driving the mill and on the right a 330 kW Ward-Leonard set.

In the same bay as the hot strip mill and directly beyond the piler is a finishing department in which the hot rolled material is processed into various commercial products. A unit is provided for de-coiling, side-trimming, levelling and shearing coiled strip into accurately squared multiple lengths.

Two tempering mills are provided for final preparation of the surface and temper of rolled sheets or rolled pickled sheets. One of these mills is arranged with an uncoiler and a tension reel for temper-rolling coiled strip steel. A continuous normalizing and annealing furnace is provided for heat treatment, and a unit is also arranged for the levelling of heavy strip.

Fig. 8.—4-high skin pass mill in hot mill. This mill can be adapted to deal with coiled strip or cut sheets. The mill itself is driven by the motor seen in fig. 9. The motor in the foreground is rated at 100 h.p. 500 volts, 300/1200 r.p.m. D.C. and drives a Fraser & Chalmers constant tension reel. The two screw-down motors are each of 7½ h.p. capacity.

Two mills are installed for the skin pass finishing after annealing of sheet and strip that require no further cold rolling.

G.E.C. ELECTRICAL AND MECHANICAL PLANT IN HOT MILL.

The plant installed in the hot mill includes a large amount of G.E.C. equipment. The mechanical plant supplied by Fraser & Chalmers Engineering Works includes two hydraulic accumulators for the supply of pressure for the roll balance on the roughing and finishing mills; also two roller levellers, with rollers 56ins. long and 5½ins. diameter complete with geared drive and approach table have been supplied, one for use with the slitting, trimming and shearing line which deals with hot rolled stock about $\frac{3}{16}$in. thick, and the other for one of the two skin pass mills which deals with sheets requiring no further cold rolling.

The other skin pass mill is employed for finishing material in strip form and is illustrated in fig. 8.

For this mill a 30in. by 68in. constant tension reel has been supplied, together with push-off gear and a 100 h.p. double reduction gear drive, which re-coils the strip after rolling. In order that this mill may be used for sheets as well as strip, a separate roller leveller and drive provided with an approach table has been supplied and can be quickly placed in position so that the sheets pass over the top of the reel and are fed direct to the leveller.

The coils of strip which have been finish rolled on the two-high skin pass mill are passed on to a side trimming and shearing line where the strip is cut into the required sizes. For use in conjunction with this plant a 5½in. by 56in. gear driven roller leveller has been supplied, also the conveyors for feeding the sheared strip to the leveller and for collecting and piling the levelled sheets.

Fig. 10.—D.C. steelworks motor of the type installed in the hot and cold mill. All motors of this type up to 25 h.p. in capacity were supplied by the G.E.C.

Electric Drives for Hot Mill.

One of the most important contracts obtained in connection with the electrification of the hot mill was the provision of all the steelworks type of D.C. motor up to 25 h.p. These motors, of which there are over 120, are of the latest type and are used to operate the approach and tilting tables, screw down gear (see figs. 6 and 7), and other auxiliary drives. One of these motors is shown in fig. 10.

In order to obtain complete interchangeability the principal dimensions—such as centre-height, shaft extensions and fixing centres—are all in accordance with the standards laid down by the Association of Iron and Steel Electrical Engineers in America.

The motors are made to withstand rough usage, heavy overloads and very rapid acceleration and deceleration. The magnet frames are split, and the top half is hinged so that it can be swung back clear of the armature (fig. 10). The armature, complete with its heavy roller bearings and housings, can then be lifted out. In this way an armature, if necessary, can be replaced with great ease and rapidity. The armatures have similar shaft extensions at each end so that the drive can be from either end according to requirements, or a brake drum can be fitted at one end.

Another important part of the hot mill contract was the complete electrical equipment for the two skin pass mills, one of which, as previously stated, is a sheet mill and is driven by a 200 h.p. 400/950 r.p.m., 230 volt, D.C. motor, while the other may be adapted to deal with either sheets or coils and is driven by a 300 h.p. 400/800 r.p.m. D.C. motor (fig. 9) and a 100 h.p. 300/1200 r.p.m. D.C. reel motor (fig. 8) with a booster, the supply for the 300 h.p. and 100 h.p. motors being obtained from a 325 kW motor generator set driven by a 500 h.p. 440 volt induction motor at 980 r.p.m. The three D.C. motors are each of the compensated type and the speed variation is obtained by shunt control.

The motor generator set and the 300 h.p. mill driving motor together with the contactor control gear, are installed in a motor room adjacent to the skin pass mill (fig. 9). The control of these mills is identical with that of the skin pass mills in the cold mill described later in this article. A diagram of the control scheme is given in fig. 11.

THE COLD STRIP MILL.

The cold rolling mill building is about ½ mile long and 480ft. wide, and contains the various mills and auxiliary plant. The building is situated approximately 1000ft. from the hot mill from which the 4- to 10-ton coils are delivered by means of a conveyor. The coils are received in the cold mill building and conveyed to storage. The first process in the cold mill is pickling to remove the scale formed on the strip by oxidation, and the pickling plant comprises two lines of picklers each approximately 700ft long. After pickling the coils pass either to a 5-stand tin-plate mill or to a 3-stand sheet mill, the two mills representing the class of products of the building, *i.e.*, tin-plate and sheet-steel. The former product is used for food canning purposes and the like, while among the important uses of the sheet steel product is the bodywork of motor cars.

Three-stand Tandem Sheet Mill.

It is in connection with the 3-stand tandem sheet mill that the most important section of the G.E.C. contract is concerned. The 3-stand mill itself is shown in the frontispiece of this issue (p. 80). The mill is of the four-high type and was supplied by The United Engineering & Foundry Co., each

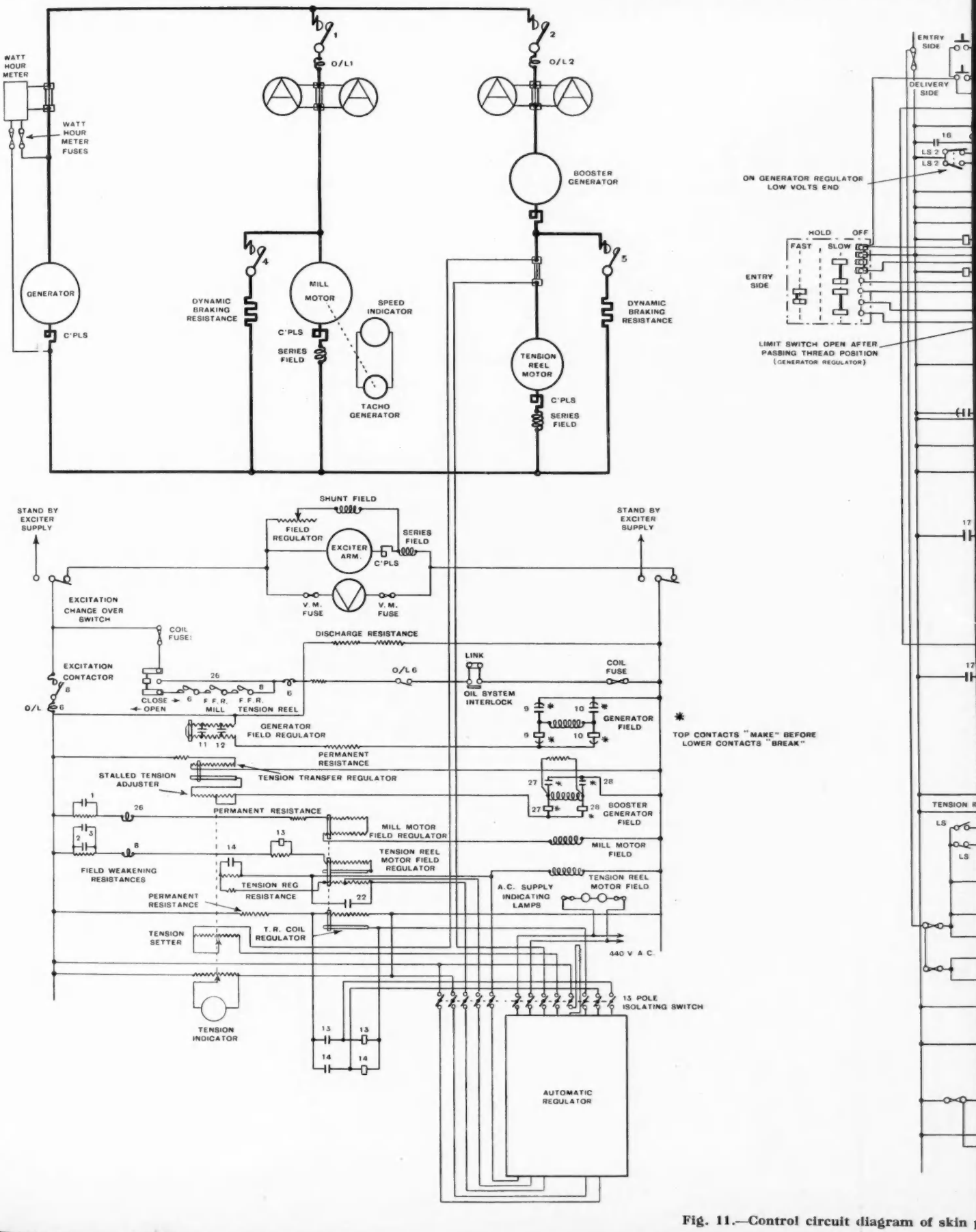
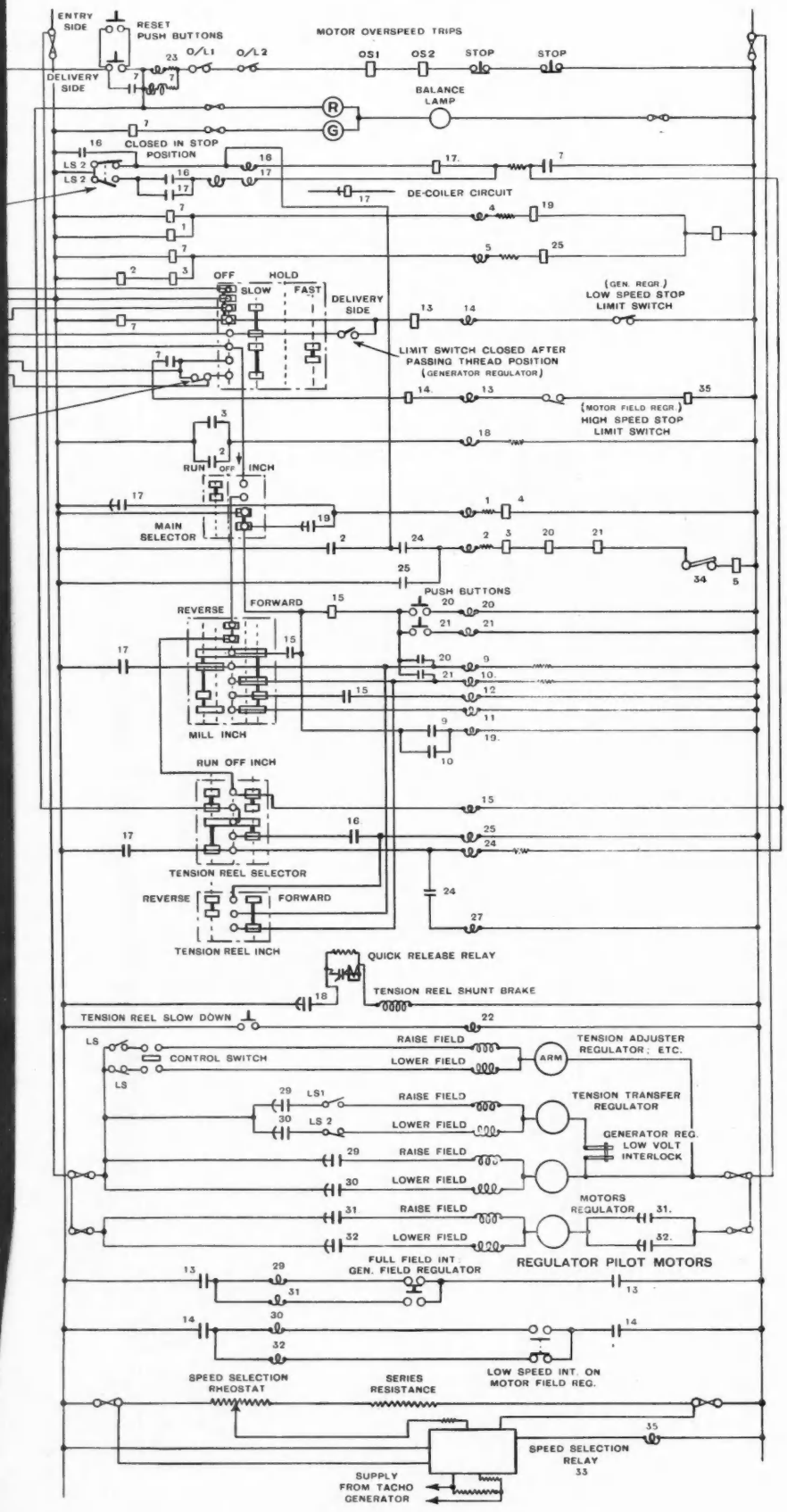


Fig. 11.—Control circuit diagram of skin p



1. MAIN MILL MOTOR LINE CONTACTOR
2. TENSION REEL .. .. ..
4. MILL MOTOR DYNAMIC BRAKING CONTACTOR
5. TENSION REEL MOTOR .. .. ..
6. EXCITATION CONTACTOR
7. SAFETY RELAY
8. REEL MOTOR FIELD FAILURE RELAY
9. MAIN GENERATOR FIELD CONTACTOR (FORWARD)
10. .. .. (REVERSE)
11. GENERATOR FIELD CONTACTOR (SLOW INCH)
12. .. .. .. (FAST INCH)
13. RAISE SPEED CONTACTOR
14. LOWER .. ..
15. MILL INCH INTERLOCK RELAY
16. STARTING INTERLOCK ..
17. RUNNING RELAY
18. TENSION REEL SHUNT BRAKE CONTACTOR
19. INCHING RELAY
20. MAIN MILL AUXILIARY INCHING RELAY
21. .. ..
22. TENSION REEL SLOW DOWN RELAY
23. AUXILIARY INTERLOCK ..
24. TENSION REEL RUNNING ..
25 .. .. INCHING ..
26. MILL MOTOR FIELD FAILURE RELAY
27. BOOSTER GENERATOR FIELD FORWARD CONTACTOR
29. PILOT MOTOR RAISE SPEED RELAY (GENERATOR)
30 .. .. LOWER .. .. (..)
31. .. .. RAISE .. .. (MOTOR)
32. .. .. LOWER .. .. (..)
33. SPEED SELECTOR RELAY
34. PERMISSIVE SWITCH (TENSION REEL)
35. SPEED SELECTOR CONTACTOR

liagram of skin pass mill.

stand having two small work rolls with two large back-up rolls. The stands are arranged so that the strip is first uncoiled and then passed through each set of rolls in series and finally re-coiled, the speed of each unit being governed to maintain a tension on the strip passing through. The mill reduces the thickness of the sheet to any required gauge between the limits of ·015 and ·078in. Each of the three stands is driven by a 1500 h.p. D.C. motor (fig. 12), controlled on the Ward-Leonard system and situated in the motor room. The reel, seen on the left of the mill (see frontispiece), is driven by a 400 h.p. D.C. motor also situated in the motor room. Views of the motor room are shown in figs. 13 and 14. On the left of fig. 13 is the Ward-Leonard set which consists of a 5000 h.p. 11000 volt 750 r.p.m. synchronous motor with a direct coupled exciter, and two 1750 kW D.C. generators. As stated previously, the driving motor is started by a metal-clad starting breaker which switches on the supply through a series reactance coil which is cut out of circuit when the set is up to speed. On approaching synchronism, a speed relay causes the excitation to be applied irrespective of the actual voltage generated by the exciter. A few seconds later the exciter voltage attains its full value and a second relay causes the "running" metalclad breaker to close which in turn trips the "starting" breaker. This system of control has been found in practice to give exceptionally smooth starting. The D.C. generators are connected in parallel to supply the 1500 h.p. motors driving the tandem mill and the 400 h.p. reel motor. Correct load sharing is obtained by means of a special equalizing connection.

A booster is also installed and is used to furnish current for "stalled tension" and inching the reel.

The three 1500 h.p. mill motors which have a speed variation of 350/700 r.p.m. obtained by shunt control, are fully compensated and are designed for close inherent speed regulation over the entire speed range. They are capable of exerting twice full load torque as an overload.

The 400 h.p. reel motor is also of the compensated type and has a speed range of 250/1050 r.p.m. Part of this speed variation is obtained by Ward-Leonard and the remainder by shunt control as in the case of the main motors.

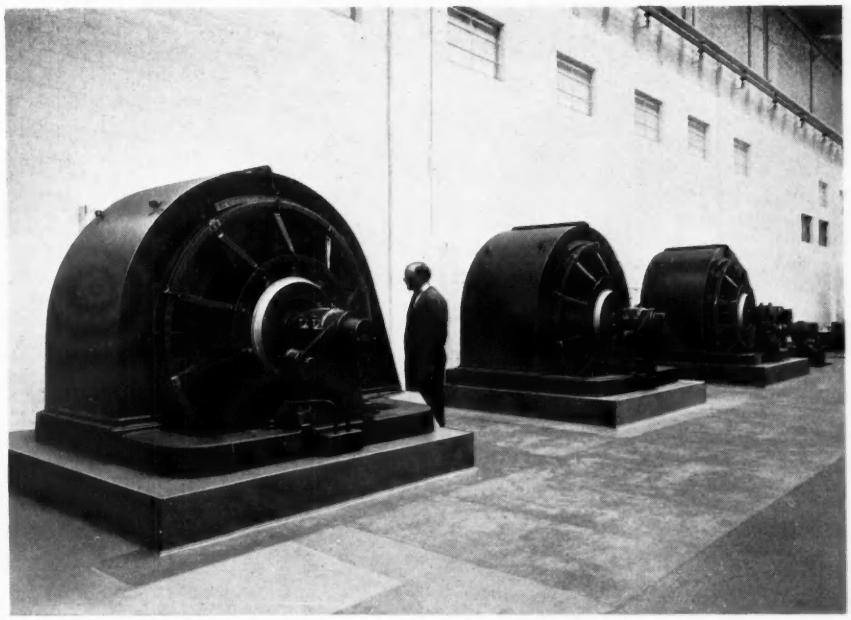


Fig. 12.—Three 1,500 h.p. 500 volt, 350/700 r.p.m. D.C. motors driving the 3-stand tandem mill in the cold mill (see frontispiece p. 80).

A separate motor generator is provided for the excitation of the main generators and the four motors just described.

A considerable amount of mechanical gear has been manufactured by Fraser & Chalmers Engineering Works in connection with the 3-stand tandem sheet mill and includes the uncoiling box, all guides for entry to and delivery from the mill rolls, a deflector roll unit over which the strip passes to the roll, the 30in. by 68in. collapsible reel for re-coiling the strip, the three sets of 1500 h.p. single reduction gear drives and universal spindles for driving the mill rolls, and the 400 h.p. double reduction gear drive for the reel.

Control of 3-stand Tandem Mill.

A very high rate of acceleration and retardation of the mill motors is necessary if full advantage is to

be taken of the high maximum speed of the mill itself (*i.e.*, 750ft. per min.) and the whole mill is capable of accelerating from a thread speed of about 50ft. per minute to the maximum in approximately 10 seconds.

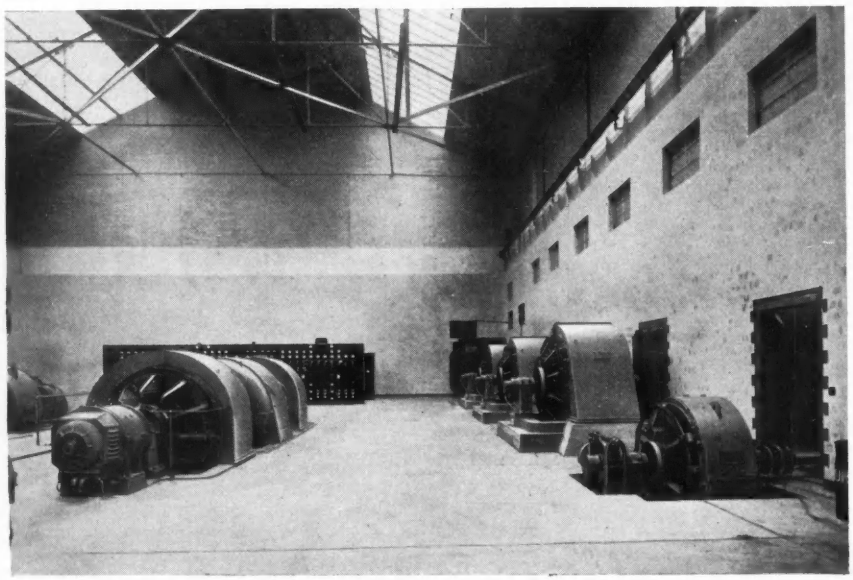


Fig. 13.—General view of the motor room in the cold mill showing on the left the 4000 kVA Ward-Leonard set controlling the three 1500 h.p. mill motors, and the 400 h.p. reel motor seen on the right.

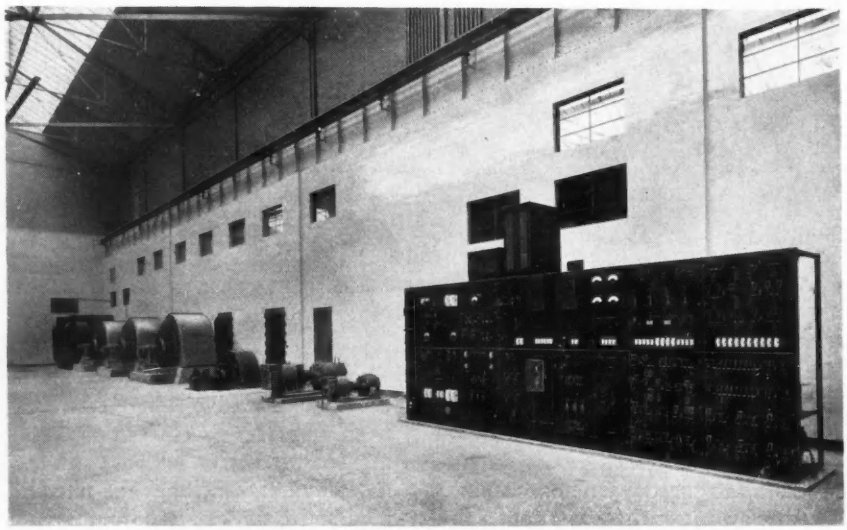


Fig. 14.—Another view in the motor room showing the 3-stand tandem mill driving motors, reel motor and main contactor board.

The high rolling speed necessitates the utmost possible convenience in control and much attention has been devoted to this in the design of the control equipment. All the mill controls are actuated by mushroom head push buttons or small pistol grip handles and are mounted on steel cabinets fixed to the mill housings at a height convenient to the operators. These cabinets are clearly seen on each stand in the frontispiece (p. 80), and one is shown in detail in fig. 15. As the controls are so numerous, it is not possible to describe them in detail but the following description gives a general outline of their functions.

The individual stands of the mill may be inched in forward or reverse directions from their own cabinets, and the whole mill, including reel, may be inched forward or reverse from the last (No. 3) stand

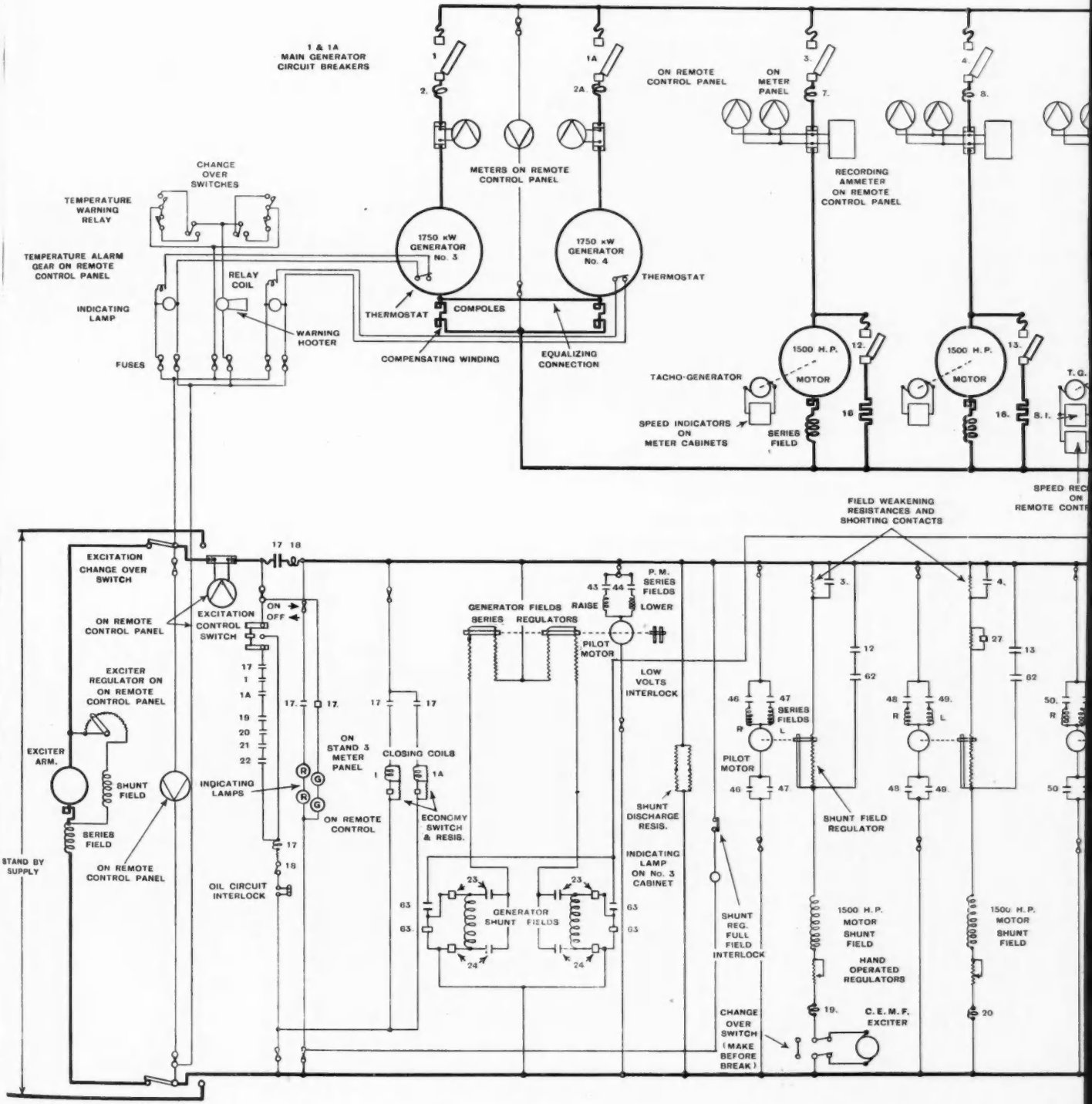
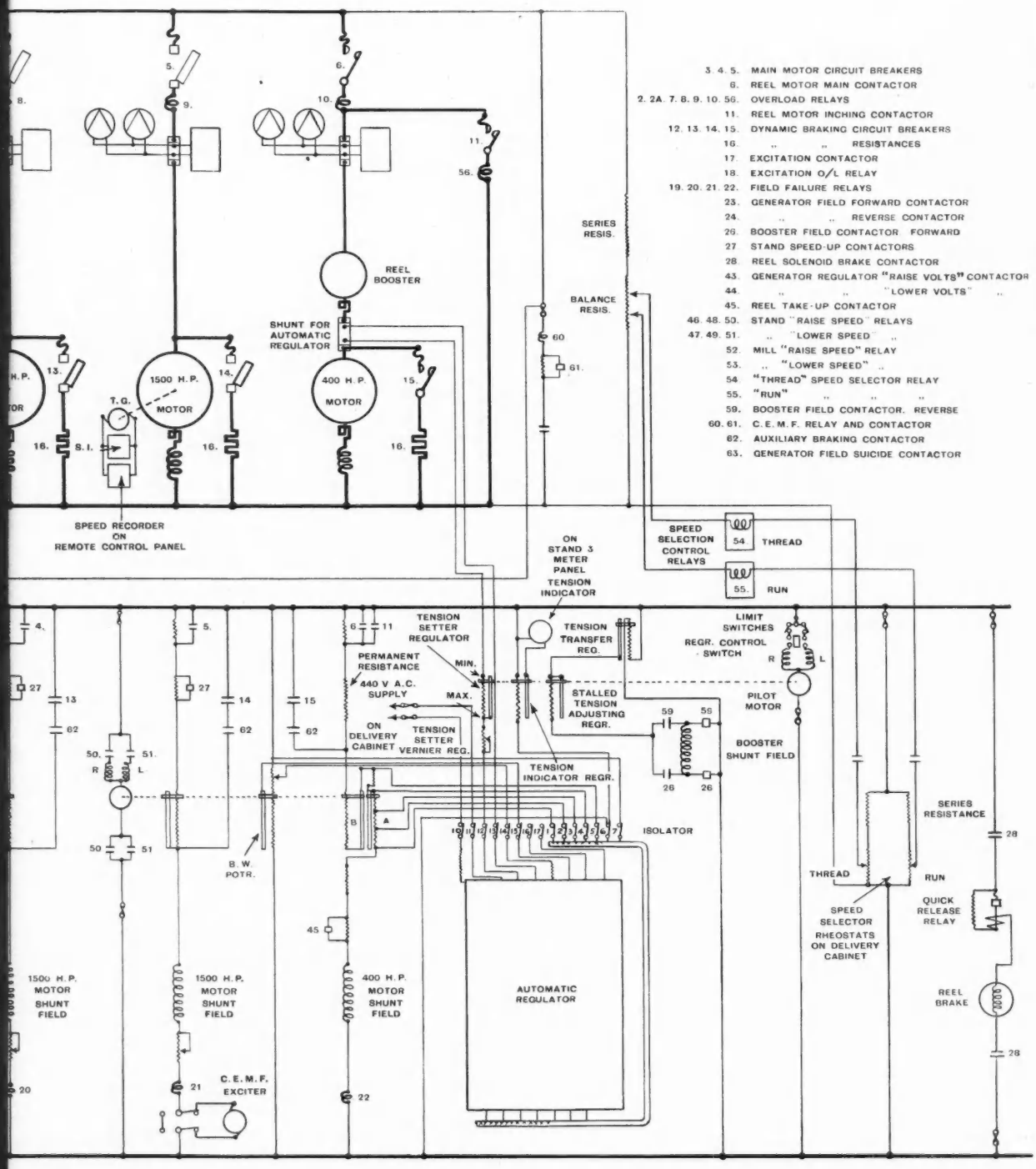


Fig. 16.—Main power circuit diagram of 3-stan



ram of 3-stand tandem mill.

control cabinet. The screw downs can be operated either singly or together at any stand. The whole mill may be run at threading speed from any stand, or accelerated to full speed or stopped under normal or emergency conditions. Speed selectors are provided at the third stand for both threading and running conditions so that the speed attained when the thread or run buttons are pressed may be pre-selected. The reel controls and meters are carried in separate cabinets.

When working at maximum output the sequence of operation is as follows. The mill is started up to run at thread speed (50-100ft. per min.) and the front of a coil is introduced into the first stand and passes through the successive stands. As it emerges from the third stand the end is inserted into the reel which is then immediately started. The reel is provided with an air brake which is applied when the reel is started and causes the reel to expand and grip the end of the strip after which the reel begins to coil. The reel slow-down push-button is pressed to minimise the shock as the slack strip is taken up by the reel and the air brake is then released. A flying micrometer is swung into position and the run button pressed, whereupon the mill accelerates rapidly to its pre-selected, or maximum, speed and continues thus with constant tension on the reel until the end of the strip approaches the first stand. At this point the operator presses the thread button and the mill slows down again to its thread speed of 50-100ft. per minute. Immediately the end of the strip emerges from the mill the reel is stopped, the air brake applied and the reel inched in a reverse direction, thereby collapsing the reel so that the coil is freed. A hydraulic stripper then removes the coil from the reel and the complete cycle of operations is started again.

Should the strip contain a bad portion or tear, it is desirable to stop the mill if possible before the fault reaches the rolls of the first stand and so avoid causing damage to the rolls. It will be appreciated in such an event that at full speed a very rapid stop will be required and the powerful dynamic braking provided enables the mill to be brought to rest in about 2 seconds.

The power circuit connections of the mill are shown in fig. 16 from which it will be seen that each mill motor and the reel motor is provided with a line contact circuit breaker or contactor. The reel has, in addition, a small series booster for control purposes and for providing a suitable inching speed. Control of the mill is effected by varying the generator voltage by Ward-Leonard control, the maximum voltage attained on pressing the mill run button being pre-selected by a small hand wheel on stand No. 3 cabinet, at which point operation of the mill as a whole is effected. The speeds of the individual stands are determined by a motor operated shunt regulator connected in each motor field and operated from the control switch at each stand cabinet.

Fine speed adjustment for each stand is obtained by means of hand-operated regulators which are used when necessary by the operators at each stand. When conditions permit of automatic running, two sets of tensionmeter gear are brought into use and automatically maintain the tension of the strip between the stands.

The ability to coil strip at a constant tension depends on the fact that a motor supplied at a voltage proportional to the mill speed and having its current maintained by a regulator at constant

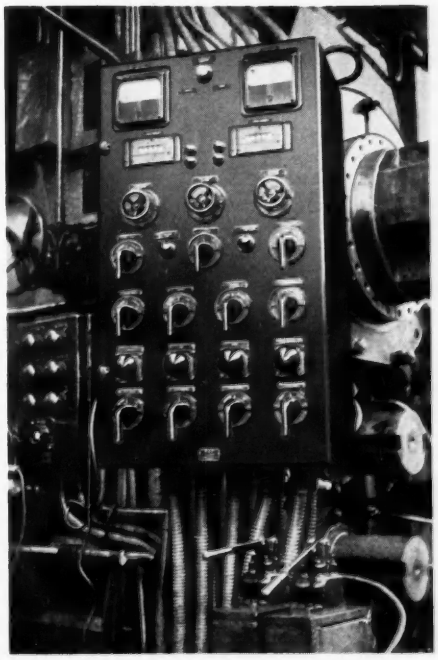


Fig. 15.—Detail view of one of the control cabinets fixed to the 3-stand tandem mill.

value, will deliver a horse power directly proportional to the mill speed. This horse power appears at the reel as the product of speed and tension in the material and as the speed of the material is the speed of the mill, the tension remains substantially constant as the reel diameter increases. The necessary conditions are fulfilled by feeding the reel motor from the generator terminals, and at the same time controlling its armature current by means of an automatic regulator connected in its field. Adjustment of the tension value is effected by altering the setting of the automatic regulator. The latter is is a standard voltage regulator adapted to work in the shunt circuit of the reel motor armature and is provided with compensating coils so that tension is maintained even during periods of changing speed.

During acceleration the reel motor has to provide not only the increasing power required for coiling the strip at constant tension but also sufficient torque to accelerate its own armature and the reel at the same rate as the mill. It is therefore necessary to increase the regulator setting by an amount proportional to the rate of acceleration, that is to say, proportional to the final speed setting, since the generator field regulators take the same time to complete their travel irrespective of the final speed setting as determined by the shunt field regulator.

Flying Shear.

After rolling in the 3-stand tandem mill, a certain proportion of the output is passed to a flying shear, fig. 17, before being annealed for further processing. Alternatively the strip may be annealed in the coil form. The flying shear which was manufactured by Fraser & Chalmers Engineering Works constitutes an important part of the equipment and is capable of dealing with strips ·05in. to ·1875in. thick and widths from 18in. to 50in. The shear is complete with a change speed and sliding crank driving gear which deals with strips travelling at a speed from 100 to 300ft. per min. It cuts these strips into sheets of any desired length. Conveyors to and from the flying shear, a 5½in. × 56in. roller leveller and gear drive, and the collecting conveyor and piler were also supplied for this shearing line.

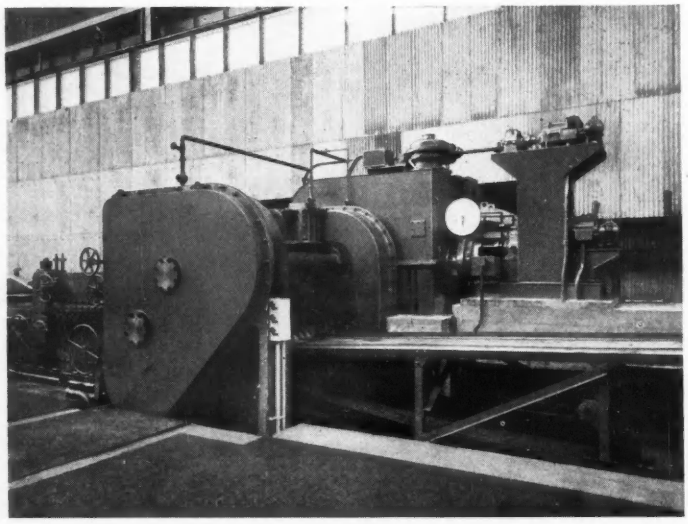


Fig. 17.—Fraser & Chalmers flying shear.

Cross Roll Mill.

A 4-high cross roll mill which deals with sheet 80ins. wide next receives the sheet and reduces it to various thicknesses. This mill is driven by an 800 h.p. 400/800 r.p.m. D.C. motor (fig. 18), which takes its supply from the 220 volt D.C. mill line. The mill is of the continuously running type and is adapted to roll sheets fed to it by means of continuously running conveyors on to which the sheets are placed by hand. Controls mounted on the mill stand are housed in hinged steel cabinets similar to those on the 3-stand mill and enable the main motor to be started, stopped, shunt controlled, inched and braked. The contactor panel which is mounted in a separate enclosure together with the motor (fig. 18) provides for light starting of the motor from the 230 volt line and gives 11 starting steps which are arranged in parallel paths to deal with the heavy starting current of 2750 amps.

The first three steps are closed under shunt lock-out control with a short time delay, the purpose of which is to supply just sufficient starting torque to cause the machine to move. Subsequent steps are controlled by a constant time accelerating relay with a final shunt lock-out control for the "running" circuit breaker. In order to ensure that starting takes place at full field, the usual shunt circuit interlocks and accelerating relays are provided together with the necessary counter-e.m.f. relays and contactors so that the machine can neither be reversed nor re-started until its counter-e.m.f. has fallen to a safe value.

Pressure of the emergency stop button on the control panel applies dynamic braking to the mill and is sufficiently powerful to bring the mill rapidly to

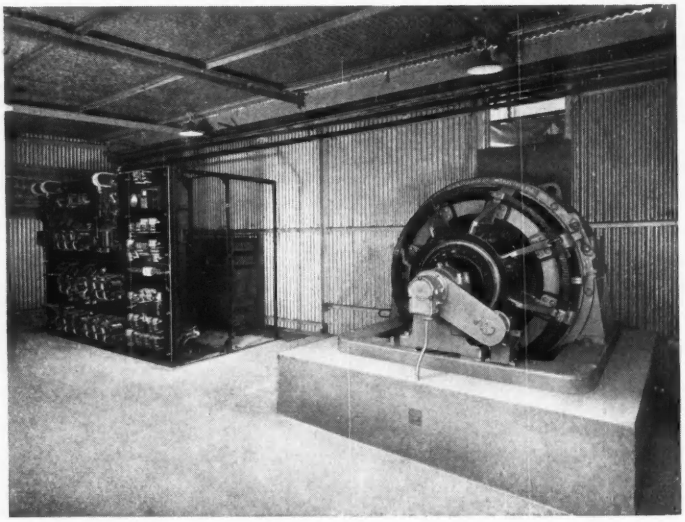


Fig. 18.—800 h.p. 400/800 r.p.m. D.C. motor driving cross roll mill. On the left is the contactor control panel.

rest. In the mechanical equipment of the cross roll mill a 4½in. by 84in. roller leveller (fig. 19) is provided complete with gear drive.

Following the cross roll mill are two skin pass mills, one of which is driven by a 200 h.p. 400/950 r.p.m. D.C. motor. This together with the control gear, which is similar in all respects to the cross roll mill just described, is of G.E.C. manufacture.

Mechanical equipment supplied for both skin pass mills includes the following :—

First skin pass mill: 200 h.p. reduction gear drives, universal spindles coupling mill pinions to rolls, entry and delivery conveyors.

Second skin pass mill: drag generator uncoiler which maintains a drag on the strip entering the mill, entry and delivery guides, deflector roll units and a collapsible reel with push-off gear.

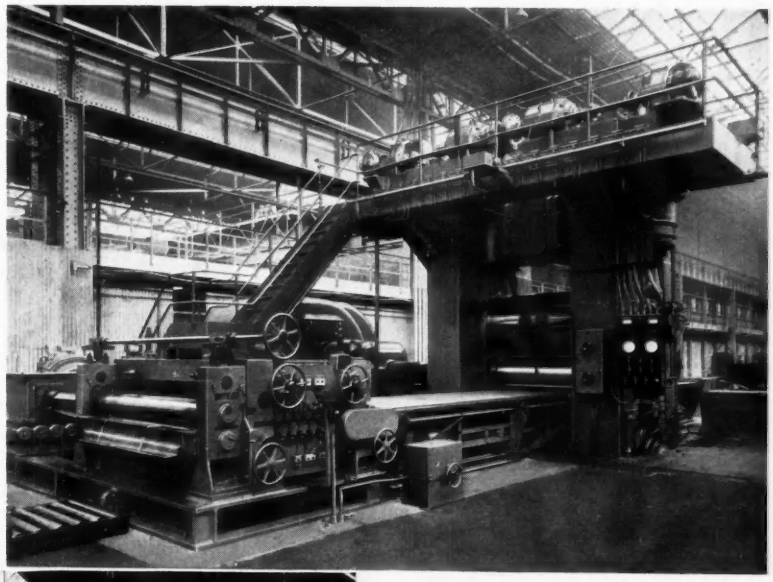


Fig. 19.—4-high cross rolling mill in the cold mill with Fraser & Chalmers leveller. This mill is driven by the 800 h.p. 400/800 r.p.m. D.C. motor seen in fig. 18.

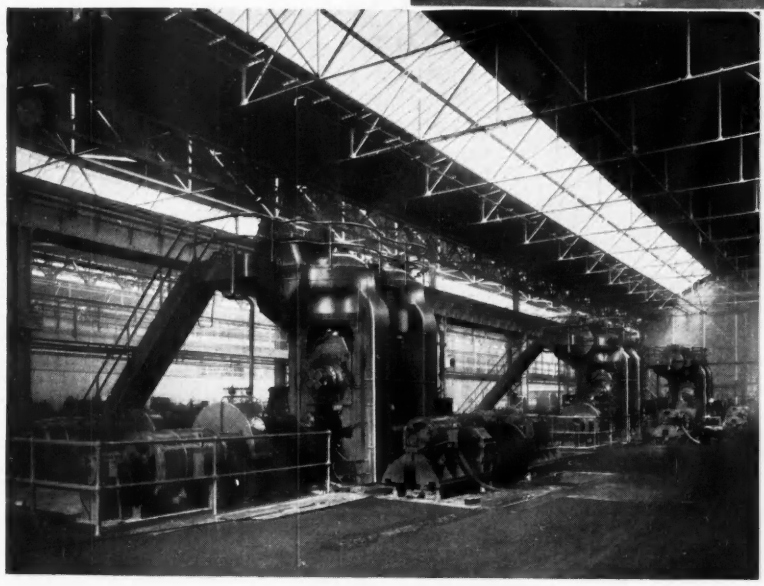


Fig. 20.—Fraser & Chalmers three single stand 4-high skin pass mills for the finishing rolling of tinplate.

PRODUCTION OF TINPLATE.

In the section of the mill which deals with the production of tinplate, the pickled coils are first passed through a 5-stand 4-high tandem mill arranged in a similar manner to the 3-stand tandem mill previously described. The equipment supplied for use with this mill comprises the five main gear drives consisting of one 400 h.p. double reduction gear, together with mill pinions and four 1000 h.p. single reduction gear sets with mill pinions ; also the five sets of universal spindles coupling the mill pinions to the rolls, the uncoiling box, guides for entry to and delivery from each set of rolls, a deflector roll unit, a 20in. by 46in. collapsing reel with its push-off gear and a 200 h.p. single reduction gear drive for recoiling the rolled strip.

Skin Pass Mills.

From this mill the coils are passed through electrolytic cleaning lines and thence to annealing furnaces, where the requisite heat treatment is given prior to the strips being surface conditioned by passing them through three single stand 4-high skin pass mills.

These three stands of 19in. and 45in. by 42in. skin pass mills (fig. 20), together with the mechanical equipment, are of Fraser & Chalmers construction and constitute a most important part of the contract. The mills are arranged so that a constant tension is maintained on the strip entering and leaving the rolls. The rolling speeds are from 450 to 900ft. per minute.

It is of interest that the six cast steel housings, two of which form one stand, each weigh approximately 55 tons.

Each set of equipment comprises the mill bedplates, housings and screw-down gear, roller bearing

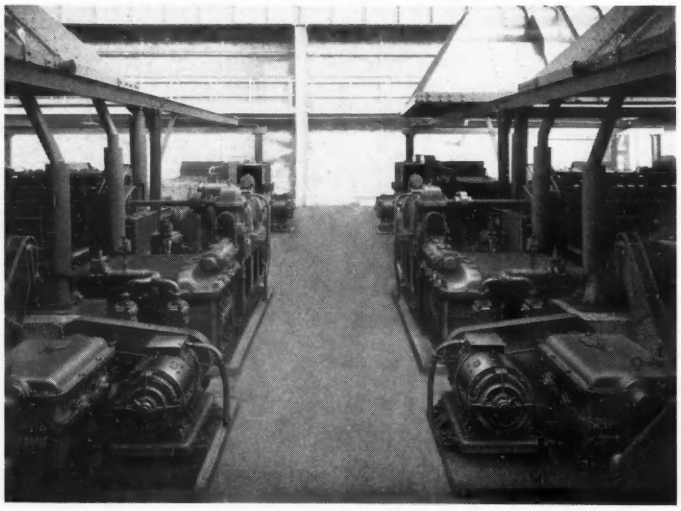


Fig. 21.—View between two of the Poole-Davis tinning equipments showing the driving motors.

fitted chocks, drag generator uncoiler, tension rolls, 20in. by 45in. collapsing reel complete with its push-off gear and 100 h.p. single reduction gear drive, 150 h.p. single reduction gear drive combined with a pair of pinions for driving the tension rolls, and 150 h.p. single reduction gear drive combined with mill pinions for driving the mill rolls, together with universal spindles for coupling the pinions to the rolls. Two hydraulic accumulators have been supplied for the roll balance of the tandem and skin pass mills.

Shearing Lines.

After skin passing the strip is recoiled and transported to shearing lines. Five cut-up lines are provided for continuously side trimming, levelling and flying shears for cutting into multiple lengths which are assorted to gauge and piled. Three of these five cut-up lines are of Fraser & Chalmers manufacture. The rolled strip is drawn through the rotary side trimming shears by pinch rolls, the scrap edges passing down through scrap cutters which cut it up into convenient pieces for handling. The trimmed strip passes through a roller leveller and a reciprocating flying shear which cuts it into sizes suitable for tin coating. Thence the sheets are taken to an automatic assorter and piler which assorts them according to gauge thickness and piles them ready for transport to the tinning department.

Sheet Tinning.

The sheet tinning equipments are of two types known respectively as the Mellingriffith and the Poole-Davis.

Eight six-way Melingriffith tinning machines are provided of the most modern British type. In each of the units the plate is automatically fed and continuously pickled, scrubbed, tinned, cleaned and piled. Each equipment is provided with four D.C. motors, two of 5/7½ h.p. and two of 15 h.p. These motors are controlled from a common automatic control panel, the push button switches being distributed between the control station on the mechanical equipment and the panels themselves so that starting and stopping the equipment are effected from the main desk while speed regulation is carried out at the contactor panels. From the control desk the motors for the blower and pump machines are also controlled.

Plate to be coated with tin in the Poole-Davis tinning equipment is pickled in a batch type white pickling plant, and loaded into water boshes for transporting by special mobile crane to the tinning machines. Nine 64in. two-way and one 75in. two-way Poole-Davis tinning machines of the latest American type are provided. In each of these units the plate is automatically fed, classified, tinned, cleaned and piled. Each unit is operated by a 15 h.p. A.C. motor and a 5 h.p. D.C. motor, both remote controlled from a control cabinet fitted with start and stop push buttons and a shunt regulator for speed control of the D.C. motor (fig. 21).

The tinned plate is taken by mobile cranes to the assorting room for inspection and grading. From the assorting room the plate is transported by mobile crane to a warehouse which is provided with automatic temperature control. Squaring shears, slitting shears, leveller, and packaging equipment are provided for final sizing and processing prior to shipment.

In conclusion the authors wish to acknowledge the kind permission of Richard Thomas & Co., Ltd. to publish this article and the accompanying illustrations.

The Applications of Electric Discharge Lamps to Photographic Processes.

By H. J. A. TURNER, B.Sc., A.R.C.S.,
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INTRODUCTION.

Up to the present time the new forms of electric discharge lamp have been prominent mainly in respect of their uses for lighting as applied to streets and factories and for advertising and decorative effects. Recent research has, however, indicated that some of these modern forms of electric discharge lamp are eminently suitable for other purposes and the results of experimental work suggest that there is a particularly wide field of application in photographic, photocopying and photo-mechanical work.

In all these processes, the fundamental purpose of light is the same, *viz.*, the production of a chemical change of varying amount in a light-sensitive material.

FACTORS AFFECTING THE APPLICATION OF DISCHARGE LAMPS.

In considering the possible usefulness of discharge lamps for photographic or allied processes, many factors must be taken into account, depending on the nature of the process and the scale on which it is carried out. The most important factors are (1) the photographic effectiveness in relation to the sensitive material; (2) the efficient utilisation of the light flux; (3) mechanical and economic considerations. In practice all these matters are interdependent.

The following are some of the new types of discharge lamp in common use at the present time which have potential application to photographic and allied processes.

High Pressure Mercury Vapour Lamps (*h.p.m.v. lamps*).[1]

Normal type (glass inner envelope) 400-W., 250-W. (quartz inner envelope) 125-W., 80-W.

Fluorescent type (with improved colour rendering) 400-W., 125-W., 80-W.

Low Pressure Lamps.

Tubular hot cathode mercury (blue) 250-W., 100-W.

Tubular hot cathode neon (red) 400-W., 150-W.

Sodium vapour (yellow) 140-W., 85-W.

Another form of lamp having a type of radiation similar to that of the low pressure hot cathode mercury type is the low pressure mercury vapour lamp. Such lamps have been in use for many years in a variety of sizes. Recently there have been developments in the direction of lamps with higher mercury vapour pressures than the normal h.p.m.v. types, both in air-cooled and water-cooled forms. In these lamps the source of light has a high intrinsic brightness and the light is whiter than that from a normal h.p.m.v. lamp. Although not in general use, they may prove to have some application in the photographic field.

The character of the radiation from h.p.m.v. lamps varies according to the type and therefore where this is a factor likely to affect the results, the type of lamp used in the actual tests has been mentioned throughout.

PRINTING PROCESSES.

The simplest photographic process is the direct production of a print by placing a transparent original in contact with a light sensitive paper and allowing light to fall on the sensitive material through the transparency. In photographic printing the transparency is a photographic negative in which the picture is formed by gradations of density from clear emulsion to a dense black. In photocopying by the blue print or some allied process, the original is a drawing of black lines on transparent paper. For carbon tissue exposure, which is an important step in commercial photogravure printing as used for illustrated magazines, high quality art reproduction and postage stamps, the sensitised tissue is exposed through a positive transparency instead of a negative.

Measurement of Photographic Effectiveness.

The photographic difference between two types of lamp depends on the character of the radiation emitted, the shape and size of the actual source of light and the radiant efficiency (*i.e.*, the total amount of radiation emitted per watt input). To compare the photographic effectiveness on a given sensitive material of light sources so diverse in nature as tungsten filament lamps and electric discharge lamps, it is necessary to obtain some measure of the amount of radiant energy falling on the sensitive material. Provided that the *luminous* efficiency of

1 This shortened description will be used throughout the text.

the lamp is known, this quantity can most conveniently be determined by measuring the visual illumination produced on the sensitive surface. The comparison is thus made initially in terms of the values for each light source of the product of visual illumination multiplied by exposure time (*i.e.*, foot candle-seconds) necessary to produce a given density of printing. It is then expressed in terms of wattage input by combining these values with the corresponding relative values of luminous efficiency of the lamp (lumens per watt). The figures then obtained represent the relative photographic effectiveness of the light sources for a given consumption of electric power.

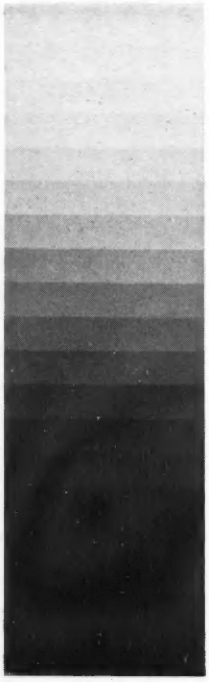

Fig. 1.—Typical print from a stepped density wedge.

A hypothetical example may be quoted to illustrate the foregoing. To produce a certain density on a photographic plate a tungsten filament lamp required an exposure of 30 seconds at an illumination of 20 foot candles. The amount of photographically effective tungsten filament radiation falling on the emulsion may therefore be measured as 600 foot candle-seconds. To produce the same density, a h.p.m.v. lamp required an exposure of 4 seconds at an illumination of 50 foot candles, *i.e.*, of 200 foot candle-seconds. Hence, taking the photographic effectiveness of the tungsten filament lamp as unity, the photographic effect of the h.p.m.v. lamp on a basis of visual illumination is 600/200, *i.e.*, three times that of the filament lamp. The discharge lamp is, however, three times as efficient as the tungsten filament lamp (giving 45 lumens per watt as compared with 15 lumens per watt for the tungsten lamp) and the photographic effect of the h.p.m.v. lamp for a given wattage input is therefore nine times that of the tungsten filament lamp.

Contact Printing and Enlarging on Standard Papers.

In normal contact printing as carried out by the photographic processing house or by the amateur, the illuminating engineering aspect of the problem is not an important one and interest is centred chiefly round the question of photographic speed.

For this work in the past, tungsten filament and small low pressure mercury vapour lamps have been used. The sensitivity of gaslight and bromide papers is a maximum towards the blue end of the spectrum and the h.p.m.v. lamp is therefore the most appropriate of the new sources for use with such papers. A comparison was therefore made between the h.p.m.v. lamp and the two older types. The method of comparison, which has already been described in the previous section, was as follows. A series of prints of a stepped density wedge (see fig. 1) were made on a representative brand of gaslight paper by exposure to each light source in turn, the value of visual illumination on the printing frame being measured. The exposure times were controlled so as to give prints of equal density. The use of a stepped wedge negative instead of simply "fogging" the paper with the light source enables the comparison to be made with more precision.

The results are given in table 1 for the relative photographic effectiveness of a 400-W. Osira h.p.m.v. type lamp and a low pressure mercury vapour lamp, taking the effect of a tungsten filament lamp as unity. The figures indicate that for bromide papers the Osira h.p.m.v. lamp and the low pressure mercury vapour lamp are about equally effective, and they are 11 to 14 times as effective as a tungsten filament lamp for a given wattage input. With gaslight papers the Osira h.p.m.v. lamp is rather faster than the low pressure lamp and both are of the order of 20 times as effective as a filament lamp. The spectra of the 250-W., 125-W. and 80-W. Osira lamps are sufficiently similar to that of the 400-W. type for the figures to be applicable to these lamps, except that the values given must be modified in the ratio of their luminous efficiencies to that of the 400-W. h.p.m.v. lamp (approximately 45 lumens per watt overall[2]).

TABLE 1.

Relative photographic effects of Osira h.p.m.v., low pressure mercury vapour and tungsten filament lamps on representative gaslight and bromide papers.

Paper	Relative photographic effect for equal wattage input		
	Tungsten filament lamp. Colour temp. 2850° K. Initial efficiency 14.4 lumens/watt	52in. low pressure mercury vapour lamp consuming 436W. Overall initial efficiency 13 lumens/watt)	400 watt Osira h.p.m.v. lamp. (Overall initial efficiency 45 lumens/watt)
Ordinary bromide paper	1	14	11
Art surfaced bromide paper	1	13	12
Gaslight paper	1	20	26

Values of initial luminous efficiency for the lower wattage types of Osira h.p.m.v. lamp are as follows:

250-watt, 36 lumens/watt.
125-watt, 40 lumens/watt.
80-watt, 38 lumens/watt.

2 Includes the wattage consumed by the choke.

All four wattage types of Osira h.p.m.v. lamps are suitable for enlargers using diffuse illumination. Their greater photographic effectiveness gives greater speed and as on this account a lower wattage may be employed for a given exposure time, less heat will be generated in the lamphouse under these conditions. Tests confirm that lamphouse and negative temperature are lower when the h.p.m.v. lamp is used than with tungsten filament lamps.

It has been suggested that the use of mercury vapour lamps affects the contrast obtained on bromide enlarging papers as compared with tungsten filament lamps. In order to investigate this point, a series of enlargements was made on various contrast grades of bromide and chloro-bromide papers using both a stepped density wedge and a pictorial negative, the enlarger being equipped in turn with tungsten filament and 80-W. Osira h.p.m.v. lamps so as to give about the same visual illumination on the paper with no negative in the enlarger. No actual measurements of contrast were made but it was found impossible to detect visually any difference in contrast between corresponding enlargements made with the two kinds of light source. Any difference which may have existed was certainly far less than that between the various contrast grades of paper ("soft," "medium," "contrasty," etc.) commercially available.

Reflex Printing.

In this process, prints of original line drawings or pages of type are made without recourse to the intermediate stage of producing a gelatine or glass negative. The original is placed with its face in contact with the sensitized surface of a piece of bromide paper. The two are arranged so that the light passes through the sensitive paper and falls on the printed surface of the original. Less light is reflected from the printed parts than from the white paper and a negative copy is thus produced. If a positive is required, a contact print is made from the paper negative. The earlier results on bromide papers will apply substantially to the type of bromide paper used for reflex printing and indicate the photographic effectiveness of the h.p.m.v. lamp for this process.

Fig. 2—Continuous photocopier using a bank of nine 400 Osira h.p.m.v. Lamps.
(By permission of Precision Photoprinting Plant Ltd.)

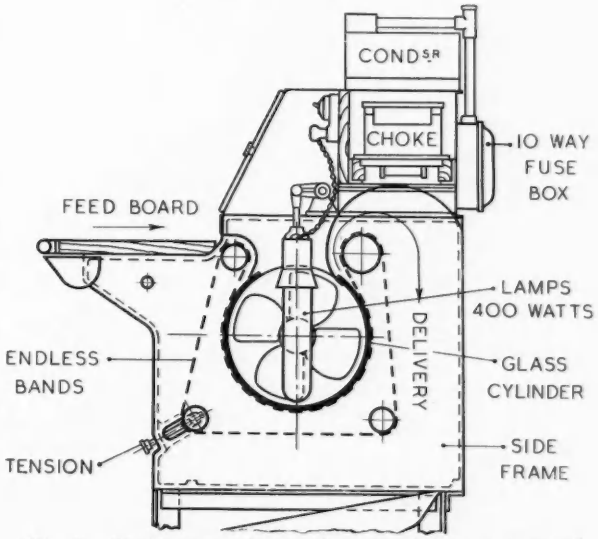

Fig. 3.—Continuous photocopier showing arrangement of lamps inside the glass cylinder.
(By permission of Precision Photoprinting Plant Ltd).

Blue Printing.

Ferroprussiate, azo dye and similar papers are sensitive mainly to blue, violet and near ultra-violet radiation. H.p.m.v. lamps are therefore suitable for use with these papers, particularly if the inner and outer glasses have a high transmission to the ultra-violet line 3650 A.U. Tests carried out to compare the photographic effectiveness of h.p.m.v. lamps with an enclosed plain carbon arc normally used on a blue printing machine showed that for equal power consumption the 400-W. Osira h.p.m.v. lamp was as effective as the arc with ferro-prussiate (blue print) papers; about one-half as effective with azo dye papers (black print on a white ground); for other types (brown and pink print on a white ground) the effectiveness varied between these two values.

There is probably no photographic material for which the carbon arc is less effective than other artificial light sources and the results have indicated that blue print papers are no exception to this. It has been stated that pure photographic speed is but one consideration in judging the usefulness of an electric discharge lamp for any given process; blue printing is a case in point.

The actual light source of a carbon arc is of very small dimensions so that at close range it is not easily possible to produce an even distribution of light over a large surface. Moreover, the shape and size of the mechanism and housing of an arc lamp make it difficult to overcome this defect either by a suitable

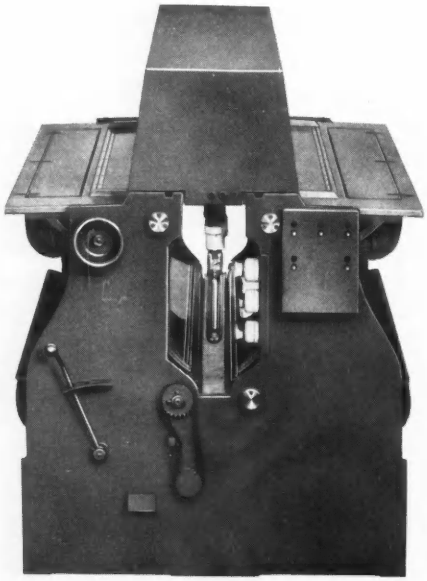

Fig. 4.—Double sided continuous copier using h.p.m.v. lamps.
(By permission of B. J. Hall & Co., Ltd.)

reflector system to redistribute wasted light flux, or by using several lamps. In practice, it is overcome mechanically by traversing the arc to and fro in the drum carrying the blue print paper. Such an arrangement has obvious disadvantages in addition to the maintenance required for the arc itself.

Full scale tests have been carried out on a rotary blue printing machine with the traversing arc replaced by a bank of 400-W. h.p.m.v. lamps. This arrangement gave promising results, but h.p.m.v. lamps may be used to even greater effect if the machine is specially designed for them, so that full use may be made of all the available light flux. Machines are now constructed which consist of a glass cylinder inside which is a bank of 400-W. h.p.m.v. lamps. The original tracing and the sensitive paper are fed round the outside of the cylinder and are thereby exposed over an angle of about 300 degrees. A machine of this type is shown in figs. 2 and 3. The latter shows the arrangement of the lamps inside the glass cylinder and the exhaust fans for cooling. A machine using the same principle, but working on a double sided arrangement, is shown in fig. 4. In this design a forced draught is provided from below the lamps.

Flat frame blue printing (using daylight as the illuminant) is restricted during winter months by the shortness of the daylight period. H.p.m.v. lamps are being used to supplement daylight for this purpose so that printing may be carried on throughout the day.

Carbon Tissue Printing for Photogravure.

The exposure of carbon tissue is a preliminary process in the production of the etched copper cylinders used for photogravure printing. Carbon tissue consists of a paper base coated with a pigmented gelatine which is sensitized by a solution of potassium bichromate. It is exposed to light through a positive transparency of the matter to be reproduced and the gelatine is thereby rendered insoluble to a depth depending on the density of the transparency. The wet tissue is then transferred to a suitable base (*e.g.* the copper cylinder), the paper backing stripped off and the soluble parts of the gelatine washed away with warm water. After this the base is etched.

For printing on a large scale such as in the production of magazines, the light source has usually taken the form of a bank of arc lamps arranged to illuminate a printing frame about 4 ft. long by 3 ft. wide. For work on a smaller scale, such as the production of carbon prints by direct transfer, either

Fig. 5.—Osira h.p.m.v. lamp unit for photogravure pigment paper printing.

a single arc or a low pressure mercury vapour lamp has usually been used. A laboratory determination of the relative photographic effects of an open flame arc, a 436-W. low pressure mercury lamp and a 400-W. h.p.m.v. lamp on a representative type of carbon tissue indicated that the h.p.m.v. lamp was

about one-half as effective for a given wattage as the arc and nearly one-and-one-quarter times as effective as the low pressure mercury lamp.

The visible light output from any lamp decreases gradually throughout its burning life. The h.p.m.v. lamp is no exception to this and after 1500 hours the light output falls on an average to about 78 per cent of its initial value. It is therefore to be expected that when in use for photogravure printing the actinic output will also decrease with life, and when the lamps have been in use for a considerable number of hours a longer exposure will be required than with new lamps. An investigation of the amount of such depreciation has been carried out at various stages in the burning life of a batch of 400-W. Osira h.p.m.v. lamps. For convenience a standard emulsion having similar characteristics to that of carbon tissue paper, *viz.*, printing out paper, was used and the results showed that, after 1500 hours burning, the photographic effect of the lamps had fallen to between 60 and 70 per cent of the initial value.

For full scale operation in the photogravure process, a unit has been constructed consisting of 6-400-W. Osira h.p.m.v. lamps in aluminium trough reflectors designed to give uniform illumination of the printing frame. The whole unit including the chokes is mounted in a frame taking the form of a trolley. Fig. 5 shows the experimental unit viewed from the front and fig. 6 from the rear when in use with a printing frame. The performance of this unit was compared with an existing installation of arc lamps consuming 85 amperes. It was found that the exposure time was reduced by one-third when using the h.p.m.v. lamp unit, and at the same time the wattage consumption was only one-half that of the arc installation. This performance may appear to contradict the results obtained on a laboratory comparison of a single arc with a single 400-W. h.p.m.v. lamp. The difference lies in the fact that with correctly designed reflectors the available light flux from the discharge lamps can, by virtue of the shape and size of the light source, be used more efficiently than that from the arcs and in addition the lighting unit can be set closer to the printing frame without impairing the even distribution of illumination over its surface.

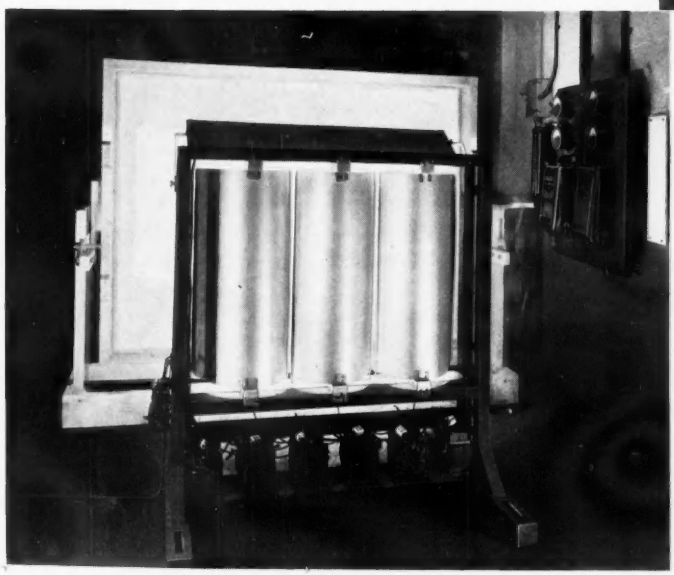

Fig. 6.—Osira h.p.m.v. lamp unit in use with a photogravure printing frame.

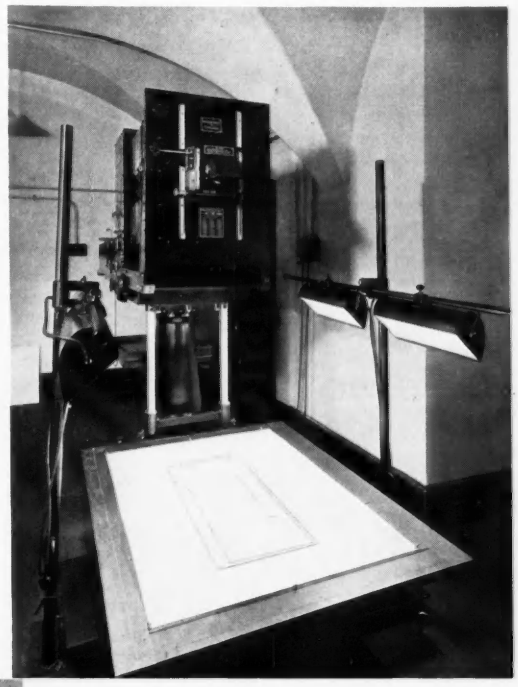

Fig. 7.—Photostat copying machine.
(By permission of The Admiralty, Central Copying Branch).

A further advantage of discharge lamps is that they are steady in operation and, unlike arcs, they do not give rise to any dust which in most printing works is a source of considerable trouble. From figures available it appears that although the capital cost of a discharge lamp installation would be rather higher than for arcs, the running cost would be reduced to about one-third of that of an installation of open-type flame arcs.[3]

Block Making.

Block making is in many respects similar to carbon tissue printing except that the sensitive material is a form of bichromated fish glue which is coated on a zinc or copper plate. No laboratory investigations on this

3 F. W. Sharp and H. J. A. Turner, "The Penrose Annual," 1939 pp. 142-145

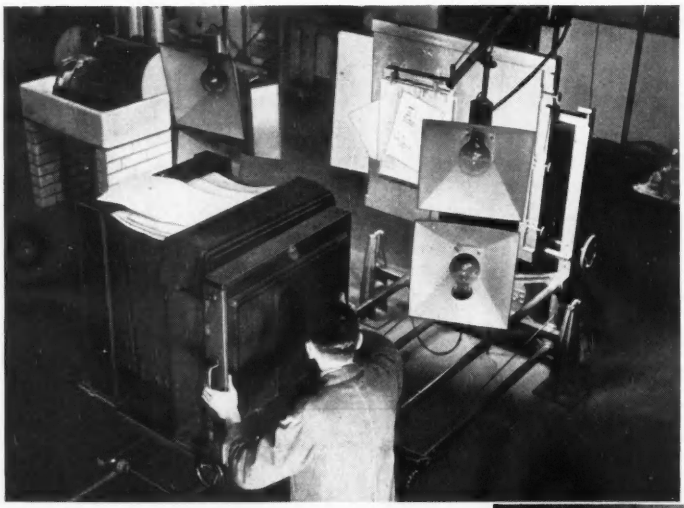

Fig. 8.—Copying camera for tri-colour separation negatives. The Osira lamp units are behind the tungsten filament lamp units which appear facing away from the camera.
(By permission of The City Engraving Company of Hull).

process have been made but some block makers are now using banks of two or three 400-W. Osira h.p.m.v. lamps in place of arc lamps.

TAKING PROCESSES.

The processes so far described are printing processes in which the light passes more or less directly through a negative or positive transparency to the sensitive material. The other main photographic process for which light is required is the "taking" process in which light is allowed to fall on the object to be reproduced and affects the light-sensitive material by the formation of an image on it by means of a lens.

In taking processes, as with printing processes, the effectiveness of any light source used to illuminate the object is dependent on the spectral sensitivity of the material on which the photographic reproduction is being made.

Photostat Copying.

The photostat copying process is a method for the rapid reproduction in either negative or positive form of originals such as patent specifications, drawings, documents or cheques. Copies of a black and white original are made as white on black, directly on a fast, contrasty bromide paper by means of a specially designed camera. A prism is used in front of the lens to reverse the

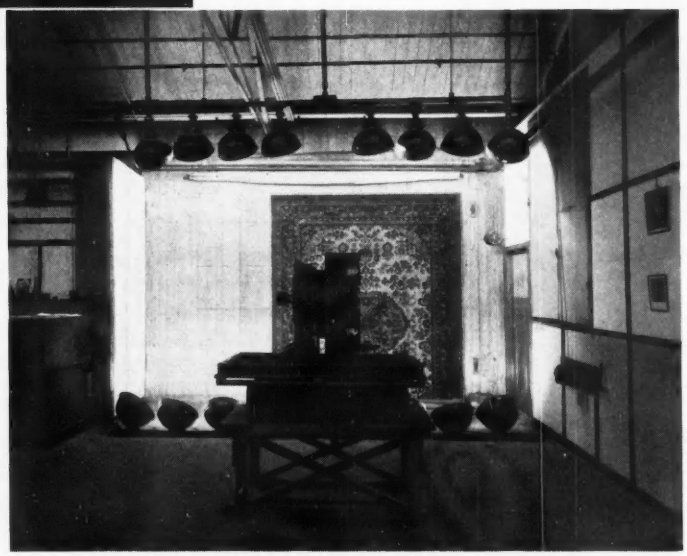

Fig. 9.—Arrangement of camera and light sources for taking separate negatives of a large coloured carpet.
(By permission of The City Engraving Company of Hull).

TABLE 2.

Relative photographic effects of high and low pressure mercury vapour lamps, sodium vapour lamps and tungsten filament lamps on representative panchromatic and orthochromatic emulsions as used on plates and films.

Plate or Film	Relative photographic effect for equal wattage input.				
	Tungsten filament lamp. Colour temp. 2850° K. Initial efficiency 14.4 lumens/watt.	52in. low pressure mercury vapour lamp consuming 436W. Overall initial efficiency 13 lumens/watt.	400W Osira h.p.m.v. lamp. Overall initial efficiency 43 lumens/watt.	400W Osira fluorescent h.p.m.v. lamp. Overall initial efficiency 36 lumens/watt.	140W Osira sodium vapour lamp. Overall initial efficiency 55 lumens/watt.
Panchromatic	1	5	5	2.5	2.5
Orthochromatic	1	17	6	Not investigated.	Negligible effect as emulsion has a low sensitivity to yellow light.

The values given for other wattage lamps will be affected by their luminous efficiency. Approximate figures may be obtained by multiplying the values given above by a factor = $\frac{\text{Efficiency of lamp under consideration.}}{\text{Efficiency of lamp given in table.}}$

image so that the negative copy will not be laterally inverted. If positive reproductions are required, they are made from a first negative copy instead of the original. The copy board, camera and processing baths are normally made as one machine which contains a continuous roll of the bromide paper so as to allow for production on a large scale if required. A complete apparatus is shown in fig. 8.

The lighting of the copy board has hitherto been mainly by low pressure mercury vapour lamps. With the object of determining the practicability of using the new h.p.m.v. lamps for this purpose, the relative photographic effects of a 400-W. Osira h.p.m.v. lamp and a 52-inch, 436-W. low pressure tubular mercury vapour lamp were measured. The result indicated that for a given wattage input both lamps had a similar photographic effect with possibly a small margin in favour of the Osira lamp. From the lighting point of view, the h.p.m.v. lamp has an advantage in the fact that its luminous column is considerably shorter than that of a low pressure lamp of the same wattage. The usual way of lighting a large copy board with low pressure lamps is by using two long lamps, one on either side. Such a long light source produces inevitably a "build up" of illumination toward the centre of the board and when a large original is being copied the resultant unevenness of lighting affects the uniformity of the copy. The replacement of each single low pressure lamp by two 250-W. h.p.m.v. lamps burning horizontally and spaced apart gives a more uniform light distribution. Moreover, with a suitably arranged reflector unit, one of each pair on either side can be cut out when copying small originals, thus effecting a saving in power consumption without recourse to separate, smaller lighting units. There are additional advantages for the h.p.m.v. lamps as compared with low pressure mercury vapour lamps in respect of a lower first cost and the simplicity of the auxiliary gear for their operation.

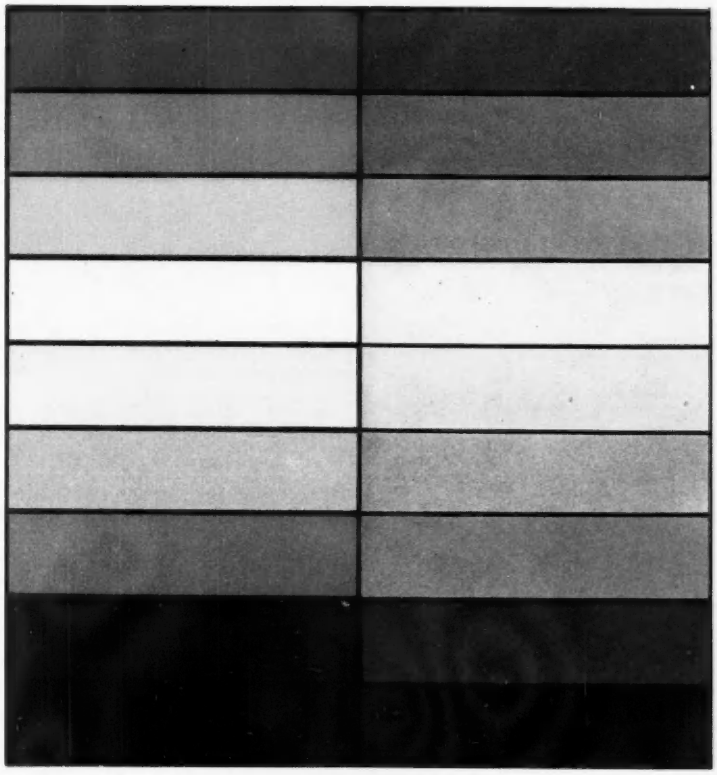

Fig. 10.—Coloured test chart.
(By permission of Ilford Ltd., London).

Standard Photographic Plates or Films.

Two factors arise when considering the photographic effectiveness of various light sources for the illumination of objects to be photographed on to plates or films. The first concerns the effectiveness, assuming the object to be uncoloured; the second, the rendering of colours into black and white. In certain classes of work this second point is of im-

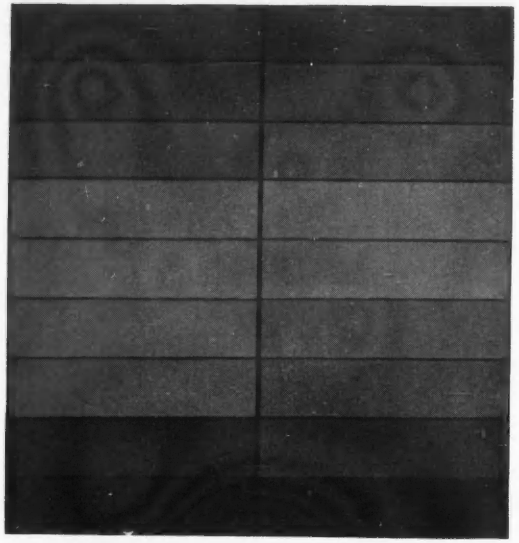

Fig. 11.—Daylight with correcting filter.

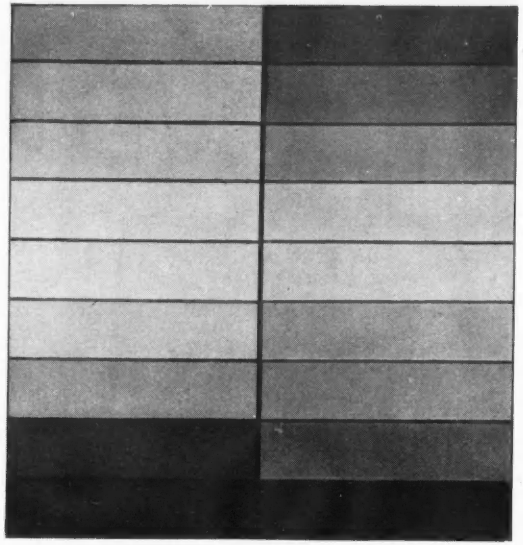

Fig. 12.—Tungsten filament lamp.

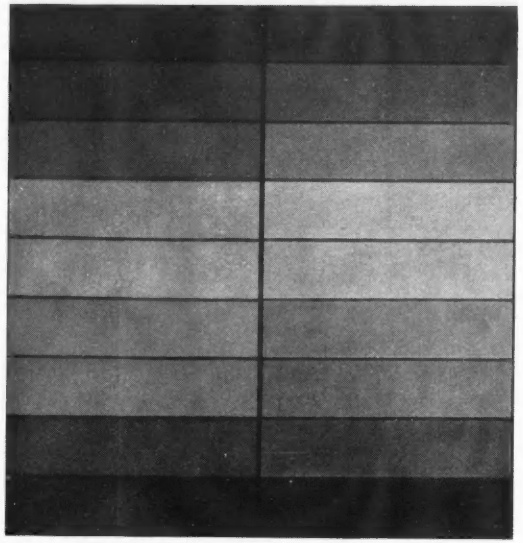

Fig. 13—400-W. Osira h.p.m.v. lamp.

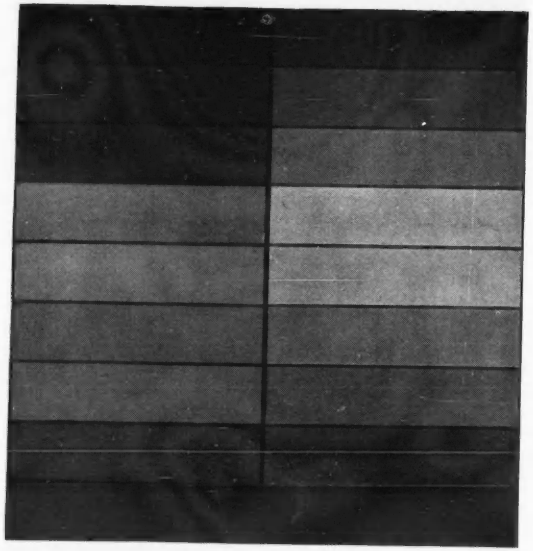

Fig. 14.—High brightness h.p.m.v. lamp.

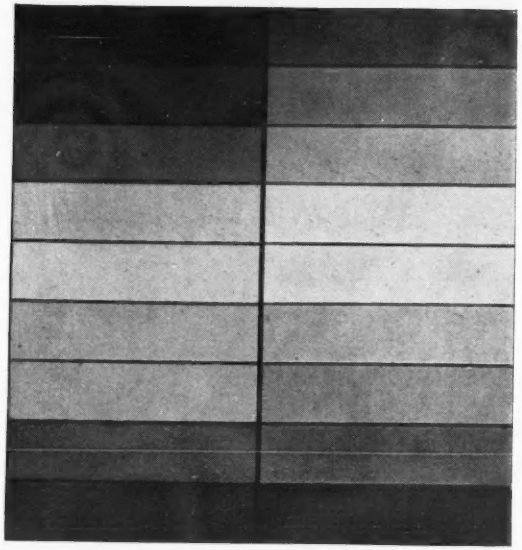

Fig. 15.—400-W. Osira fluorescent lamp.

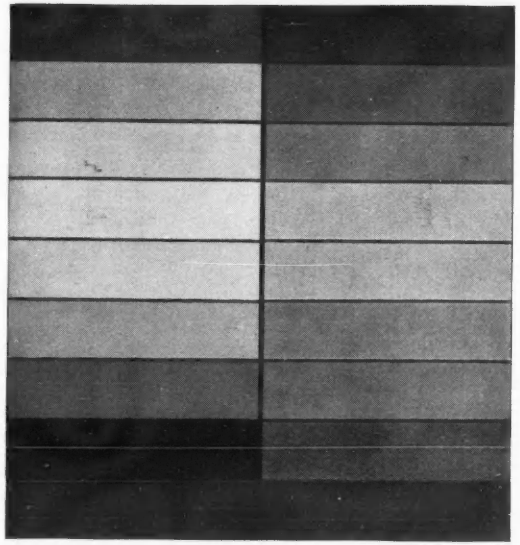

Fig. 16.—Osira sodium vapour lamp.

Figs. 11 to 16.—Reproductions of coloured test chart (fig 10) illuminated with daylight tungsten filament, mercury vapour and sodium vapour discharge lamps ; photographed on panchromatic plates.

portance and a separate section will therefore be devoted to it.

Laboratory measurements have been made to determine the relative photographic effects of normal h.p.m.v., low pressure mercury vapour, fluorescent h.p.m.v., sodium vapour and tungsten filament lamps with typical emulsions as used on standard plates and films. The method of test consisted in making equal density copies on the emulsion concerned of a print of a stepped density wedge, the wedge being illuminated in turn by each light source. The exposures were measured in foot-candle seconds, *i.e.*, the product of the illumination on the wedge print and the exposure time in seconds, and were afterwards correlated with the luminous efficiency of the lamps to give the relative photographic effectiveness in terms of equal wattage input into the lamps. The results are given in Table 2, from which it appears that with panchromatic emulsions both types of mercury vapour lamp were five times as effective as a tungsten filament lamp and the fluorescent lamp two-and-a-half times. In the case of orthochromatic plates, the low pressure mercury lamp is three times as effective as the 400-W. Osira h.p.m.v. lamp and the latter, six times as effective as a tungsten filament lamp.

Tri-colour Separation Negatives.

Three-colour process work involves the preparation of three half-tone blocks, each of which will print a separate colour in the copy so that a full coloured reproduction results. These blocks are made from negatives prepared by photographing the original in the normal way, each photograph being taken through a red, blue or green filter on panchromatic plates or films.

For the illumination of the original, both arcs and tungsten filament lamps have been in common use; the former have the requisite spectral characteristics for this work but have the mechanical disadvantages usually associated with arcs. Tungsten filament lamps are convenient but the deficiency of radiation at the blue end of the spectrum involves lengthy exposures for the blue and green colours. Osira h.p.m.v. lamps, although lacking in red, are being used successfully when taking the blue and green negatives. Fig. 8 shows a typical arrangement of copy-board and camera, the lighting units in this case consisting of a double set of reflectors, one set housing Osira h.p.m.v. lamps for use when taking the blue and green negatives and the other set (not shown in the illustration) for taking the red negative. Fig. 9 shows the arrangement of the lighting units when a large original is being photographed.

Recent work has indicated the suitability of hot cathode neon floodlighting lamps for the red negative, their photographic effectiveness being about 1·7 times that of 200-W. tungsten filament lamps for a given wattage input on process panchromatic emulsions with a red tri-colour filter.

Quite recently, the Osira fluorescent (colour corrected) h.p.m.v. lamp has been used successfully for illuminating the copy when making all the separation negatives but laboratory results on photographic effectiveness are not available.

THE REPRODUCTION OF COLOURS IN MONOCHROME ON PANCHROMATIC PLATES.

Most black and white photography involves the recording of colours in black and white and the quality of the reproduction is normally judged by comparison with the daylight appearance of the original. There is no "standard daylight" in general use and even the usually quoted "north light" varies considerably with local conditions and the season of the year. It appears, however, that the eye can judge to within fairly close limits the correctness of reproduction of colours in monochrome by a comparison of the brightness of the various colours reproduced in the monochrome record with the brightness of the originals.

Orthochromatic plate or film emulsions, which were at one time the only types available, were lacking in red sensitivity, and even with subjects illuminated by daylight it was common to see deep red colours reproduced as dark shades and light blue colours as light shades.

Shortly after the introduction of the 400-W. h.p.m.v. lamp, some experiments were carried out to ascertain its colour rendering properties on panchromatic film. The 400-W. h.p.m.v. lamp lacks sufficient red radiation to be used alone, and these experiments were confined to combinations of h.p.m.v. lamps with tungsten filament lamps. The results showed that a mixture of light from 200 watts to 600 watts of tungsten filament lamps with a 400-W. Osira h.p.m.v. lamp rendered colours in the same relative brightnesses as seen in daylight. Lighting units were therefore frequently employed in which one 400-W. Osira h.p.m.v. lamp was used with two 200-W. tungsten filament lamps.

With the introduction of h.p.m.v. lamps giving a greater proportion of red radiation than the normal lamps, either by use of fluorescent powders on the bulb or by increasing the mercury vapour pressure, the question was re-examined to find out whether or not renderings equivalent to daylight could be obtained with a single discharge lamp. To make the experiment comprehensive, the tests on tungsten filament and normal h.p.m.v. lamps were repeated, although the effects of these lamps were already known. The test object used was the well known Ilford colour Test Chart, a reproduction of which is shown in fig. 10. This consists of a strip of nine coloured bands ranging from red to violet.

Figs. 11 to 16.—Reproductions of coloured test chart (fig 10) illuminated with daylight tungsten filament, mercury vapour and sodium vapour discharge lamps; photographed on panchromatic plates.

Fig. 17.—Daylight illumination with correcting filter.

Fig. 18.—400-W. Osira fluorescent lamp.

Fig. 19.—Tungsten filament lamp.

Figs. 17 to 19.—Coloured flowers illuminated by daylight, mercury vapour discharge lamps and tungsten filament lamps; photographed on panchromatic plates.

Corresponding to each coloured band is a monochrome band whose density is so chosen that its brightness is the same as that of the corresponding coloured band illuminated by daylight.

The first test was made by photographing the chart under daylight illumination, using a correcting filter which is designed so that with the appropriate panchromatic emulsion the brightnesses of the coloured strips are reproduced in the same ratio as their visual brightness in daylight. Fig. 11 is a reproduction of the photograph and as the reproduced brightnesses of the coloured and monochrome sections of the chart are almost identical, the result may be considered good.

Fig. 12 shows the coloured chart photographed under light from tungsten filament lamps and fig. 13 under light from a 400-W. Osira h.p.m.v. lamp. These two are of interest in that whereas the h.p.m.v. lamp gives considerable visual colour distortion of red and yellow and a similar photographic distortion as well, the tungsten filament lamp which is generally regarded as acceptable from the visual standpoint gives a photographic distortion at the blue end of the spectrum of nearly the same amount. There are standard filters available for the correction of tungsten filament light but their use reduces the photographic effectiveness of the light source to one quarter, as a result of the absorption of the filter.

Further experiments using higher brightness types of mercury vapour lamps were carried out and the results in general followed the visual impression that as the mercury vapour pressure and brightness increased the colour distortion decreased as a result of the increasing red content from the continuous background in the spectrum. One of these is illustrated in fig. 14, which shows the chart illuminated by means of an experimental higher pressure mercury vapour lamp having a brightness twenty to thirty times that of the normal h.p.m.v. lamp. The next step was to investigate the effects from the alternative method of colour correction, viz., the fluorescent lamp. Tests on a 400-W. Osira fluorescent h.p.m.v. lamp indicated that renderings almost identical with the visual brightness as seen in daylight were obtainable. Fig. 15 shows a photograph of the colour chart taken under a 400-W. fluorescent h.p.m.v. lamp. This result indicates a possible application of the fluorescent lamp for record work where colour rendering is of importance. It has the advantage that a single light source can be employed and the light has a greater photographic effectiveness than tungsten filament lamps.

To illustrate this point, some further photographs on panchromatic plates of a vase of highly coloured flowers were taken. This subject included scarlet, deep pink, flame and yellow tulips; cornflowers,

violets, pale mauve irises and the foliage. The photographs were taken under entirely diffuse lighting, the situation of the sources, matt white reflector and camera being the same in each case.

yellow has almost disappeared. The effects are particularly noticeable in the flowers on the left of the illustrations.

It has already been shown that the fluorescent

Fig. 20.—Daylight with corrective filter.

Fig. 21.—Tungsten filament lamp.

Fig. 22.—400-W. Osira h.p.m.v. lamps.

Fig. 23.—Water-cooled h.p.m.v. lamps.

Fig. 24.—Sodium lamp.

Fig. 25.—400-W. Osira fluorescent lamp.

Figs. 20 to 25.—Reproductions of sitter illuminated with daylight, tungsten filament, mercury vapour and sodium discharge lamps ; photographed on panchromatic plates.

The illuminants used were daylight plus a correcting filter (fig. 17), tungsten filament lamps (fig. 19) and fluorescent lamps (fig. 18). The results confirm directly those obtained with the colour chart. It will be seen that the reproduction under the fluorescent lamps is practically identical with that under daylight, while with tungsten filament lamps the distinction between the various shades from red to

lamp is about two-and-a-half times as effective as a filament lamp on panchromatic plates and since with the latter a times-four correcting filter must be used to obtain correct colour renderings, the photographic effect of the fluorescent lamp is increased to ten times that of the tungsten filament lamp.

Fig. 16 shows the test chart when photographed under light from a sodium vapour lamp. The

radiation from sodium vapour consists entirely of yellow light, so that only yellow colours can be reproduced correctly. This result is of interest in connection with lighting for portraiture which is dealt with in the next section.

Fig. 26.—Prismatic plate lens spotlight.

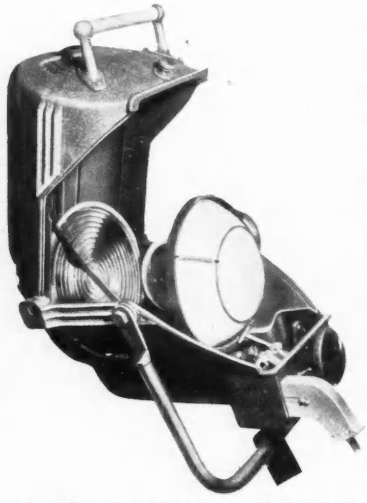

Fig. 27.—Spotlight opened showing lens, lamp and backing reflector.

Portraiture.

A natural development of the work on the rendering of pigment colours was an examination on similar lines of the rendering of the human complexion. This problem is a more difficult one because judgment of a portrait is not based solely on the truth or otherwise of the monochrome rendering of lips, eyes, hair and skin texture. It depends also on the directional characteristics of the lighting, the degree of diffusion, the density of the final print and even the expression on the sitter's face. With these considerations in mind, a series of portraits of a sitter were taken using various discharge and tungsten lamps as illluminants with the variable factors controlled as far as possible. The positions of sitter, camera and light source were kept constant and in the same room throughout. The amount of diffusion and the visual illumination were also kept constant as far as was practicable, although this was a matter of some difficulty when dealing with light sources so diverse in shape and size.

In the field of portraiture, it is difficult to know which result to take as a standard of comparison. Tungsten filament lamps are still the most commonly used light sources in portrait studios and it might seem that a photograph taken under filament lighting should be adopted as the standard of comparison. On the other hand, one is at least as accustomed to seeing human faces by daylight as by artificial light.

In making a comparison between the various results, therefore, no particular one will be taken as a standard, and comparisons will only be made with the object of drawing attention to the differences between them. It remains for the photographic artist to choose the light source which gives him most nearly the result he desires ; the illustrations are used to this end and do not pretend to be artistic studies.

Fig. 20 shows the sitter photographed in daylight with a correcting filter, and fig. 21, under light from tungsten filament lamps. With daylight, the skin blemishes appear somewhat exaggerated, but with tungsten filament light they are suppressed to an extent which gives the face a "pasty" appearance. In addition, the lips are pale as a result of the high proportion of red in the light and the eyes are lacking in life.

With normal Osira h.p.m.v. lamps (fig. 22), the skin blemishes are, as would be expected, much exaggerated, and the lips are too dark. With h.p.m.v. lamps of higher brightness (fig. 23) the colour rendering is improved and tends to approach more closely to that of daylight, although, in general, the reproduction is not very pleasing.

A further type of lamp investigated was the sodium vapour lamp. Although the light from this lamp is practically monochromatic in its radiation and

Fig. 28.—Reflector type studio spotlight.

Fig. 29.—"Broadside" type studio lighting unit.

produces considerable colour distortion, both visually and in the photography of coloured objects, these limitations are not marked when the lamp is used for portraiture. Fig. 24 shows the results obtained with a sitter. The renderings of lips, eyes and hair are not correct, but this is not always essential in portrait work.

The closest approach to the daylight appearance is obtained with a 400-W. Osira fluorescent h.p.m.v. lamp (fig. 25). The skin texture appears sufficiently prominently to give it character, the lips are appropriately dark and the eyes have a depth of tint which corresponds to their daylight appearance.

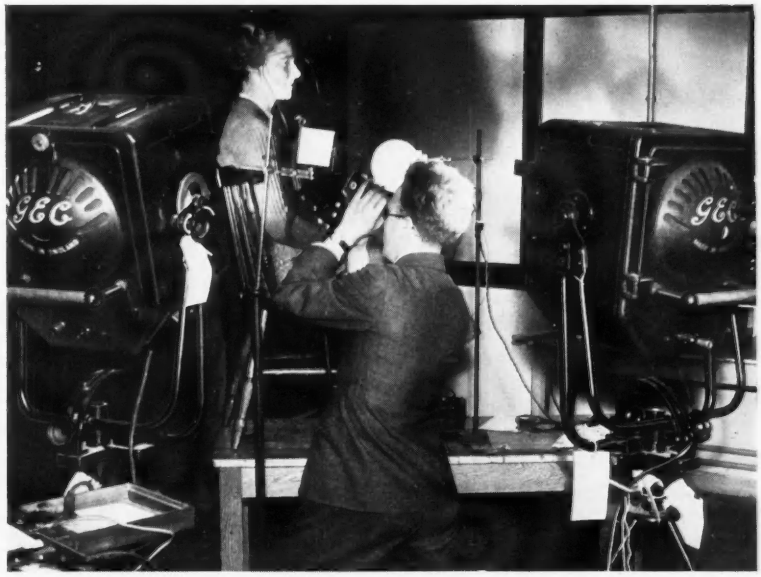

Fig. 30. Temperature tests on the skin. The thermo-couple for measuring temperature is strapped to the subject's forehead.

STUDIO LIGHTING EQUIPMENT.

For practical use in the studio, some housing is required for the lamps and this can combine with advantage redirection of the light so as to obtain as great a proportion of the bare lamp light as possible on the sitter or object.

The most convenient source to control is the tungsten filament lamp and in addition to the various types of diffuser unit for general diffused lighting, there are now available units which give at will, narrow or wide controlled beams of light. Fig. 26 illustrates a typical unit for use with a 2 kW tungsten filament lamp. The light is controlled by a prismatic lens and by moving the lamp, the beam width can be varied from two feet to ten feet at a distance of ten feet from the unit. The lens is so designed that even in the wide-spread position, the illumination is uniform throughout the beam width, and the bright core or bright annular ring so often obtained with a simple spotlight is absent. Fig. 27 shows the accessibility of such a unit when open.

In a second type of unit illustrated in fig. 28, the light control is obtained by means of a large, lightly stippled reflector of ellipsoidal contour behind the lamp with louvres in front to cut off spill light. Even illumination over the area of the spot is ensured by the use of a graded diffusing front glass.

With the normal h.p.m.v. lamp, combinations of this lamp with tungsten filament lamps and the fluorescent h.p.m.v. lamp, it is not possible to obtain a concentrated beam on account of the source size, and such light sources are commonly used in a broadside unit as illustrated in fig. 29.

When extremely high values of illumination are required, the heating effect from tungsten filament lamps sometimes proves a difficulty. It would be expected that on account of the high photographic effectiveness of h.p.m.v. lamps, less heating would be obtained with these lamps, particularly when the light passes through a glass lens or plate before reaching the subject. The reason for this is that the heat radiation from discharge lamps comes largely from the heated envelope round the discharge. Such heat radiation has a longer wave-length than that from a tungsten filament which is operating at a much higher temperature than the glass or quartz envelope; it is therefore absorbed more completely by a glass lens or plate.

Tests of the temperature rise of the human skin with 1,000 foot-candles of tungsten filament light, h.p.m.v. lamp light and carbon arc light, after passing through a glass lens, have been made in the manner shown in fig. 30. The temperature is measured by means of a thermo-couple strapped to the sitter's forehead. The approximate temperature rise of skin per 1,000 foot-candles was found to be 2·4°C. with a tungsten filament lamp and 0·6°C. with a high pressure, high brightness mercury vapour lamp.[4] The temperature rise per 1,000 foot-candles for the arc was deduced from a later test to be about one-half that obtained with the tungsten filament lamp. It was found during these experiments that the tungsten filament lamp caused considerable discomfort at illumination values of 2,000 foot-candles after only a few minutes' exposure, whereas it was possible to remain almost indefinitely under mercury vapour lamp light, even at illumination levels of 6,000 foot-candles.

4 W. R. Stevens, Journal of the British Kinematograph Society, Vol. I, pp. 158-171, Oct., 1938.

The New Sound Measurement Building at Witton.

WITH SPECIAL REFERENCE TO THE MEASUREMENT OF NOISE IN ELECTRICAL MACHINERY.

By H. JACOBY, M.I.E.E.
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SOUND MEASUREMENTS.

THE elimination of noise made by machinery is a problem which is receiving considerable attention at the present time. To achieve the desired result, it is necessary to have some mode of reference to the volume of sound produced and hence much thought has been given of late years to devising better methods of measuring sound. The loudness of a sound caused by a given source such as a machine or other sound producer will be affected to a very large extent by the environment of the source of sound, and by the position and environment of the measuring instruments. It is the purpose of the following article to point out the effects of the environment, and to show the necessity for a special room in which all comparative noise measurements may be taken.

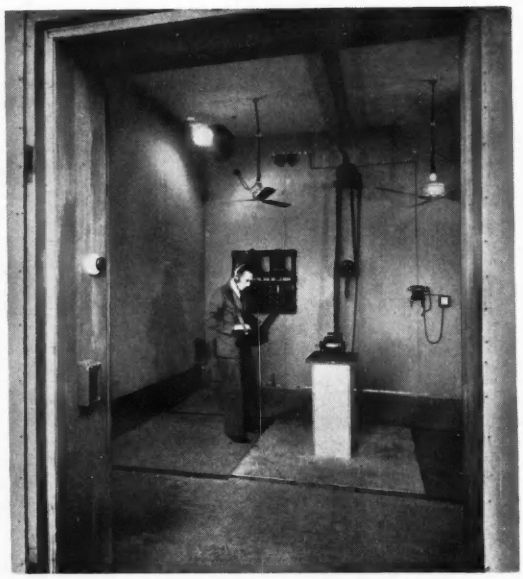

Fig. 1.—Noise test on a small electric motor in progress in the sound measurement building.

Greatly improved instruments are now available for sound measurement, and a new unit, the phon, has recently been standardized. These instruments may be broadly divided into two classes: the subjective type and the objective type, each of which measures the loudness of sound in phons. The first uses the ear as arbitrator to determine the equality of two sounds, and measurements are made by listening in a pair of calibrated headphones to a sound called the reference tone, which is artificially generated, usually by means of an oscillating valve.

The volume of the reference tone can be adjusted to any degree within the usual limits of hearing. The adjustment is made by means of manual tuning knobs as in a wireless set, and the volume is varied until the operator judges that the noise in the headphone is equal to that being measured. When this has been done, the position of the knob gives the intensity of air pressure in the headphone, the instrument having been previously calibrated so that the scale reading on the dial indicates the sound pressure in the headphone. The scale is usually marked in decibels above a given reference level. Since loudness is a function of the human ear, this method of measurement gives a true result in terms of the ear of the particular operator, and is thus open to the objection that two operators may not agree on the measurements, or that the same operator may get different results on different occasions due to change in the acuteness of his hearing, which may be found to vary not only from day to day, but also from minute to minute. However, remarkable agreement is usually obtained by various operators once they are used to the work.

The other type of instrument referred to is the objective type, the measurements being indicated by a pointer moving over a scale so that a positive reading is obtained. In this type the sound is picked up by a suitable microphone connected to an amplifying circuit, the instrument being so calibrated that the reading of the output meter corresponds to the sound pressure on the microphone.

When the instrument is required to read in phons, the circuits must be weighted, that is, so adjusted that the readings of the output meter correspond to the arbitrament of the average human ear. In general, this can only be done imperfectly. Hence, this type of instrument is not usually as satis-

factory as the subjective type when measurements of total loudness are required.

In other types of objective instruments the circuits are so tuned that, for each tuning, the sound pressure corresponding to that particular frequency only is measured. To use the instrument, the maximum readings are recorded for each audio frequency which gives an indication on the instrument. By this means, each note in the noise is recorded separately, so that an analysis of the noise is obtained. This type of instrument is more suitable for sound analysis, and is not so well adapted as the other types for measuring the total volume of sound in phons.

All three types of instruments record either the actual or the equivalent sound pressure at the locus in space at which the measurements are taken, and not the total sound energy generated by the source of sound. The loudness of the sound produced by a given source such as a machine, a musical instrument, a siren or any other cause of sound, will depend upon :

(1) The nature of the sound producer.
(2) The nature of the building in which the sound is made.
(3) The resonance of the supports on which the sound producer is placed.
(4) Any other resonance in the building.
(5) The value of the measurements will also depend upon the relative location of the sound producer and the measuring instruments.

The attenuation will also be affected by the sound properties of the building. In consequence of this, it is necessary when stating the measured level of noise to give, in addition, the exact condition under which the tests were taken. Furthermore, the presence of noises other than that being measured will interfere with the results and, unless these background noises are small in comparison with the noise being measured, they will make any reliable results impossible.

For these reasons it is necessary, if any degree of accuracy and reliability is to be obtained, to provide a special silence chamber in which all comparative measurements may be taken. For example, the results of sound measurements made on a certain piece of electrical apparatus in different types of buildings are shown by the curves in fig. 2. The measurements were made with a subjective type of instrument, care being taken to see that, except for the environment, the apparatus was working in each case under identical conditions.

Before proceeding to describe the G.E.C. sound measurement building which has lately been built at Witton for the purpose of investigating the noise made by electrical machinery, it may be as well to give a brief statement of some of the properties of sound in so far as they affect the measurements of sound intensity.

Loudness is a physiological function of the human ear, and since the effect is upon the mind it cannot be expressed in ordinary physical units. It is, however, possible to measure the stimulus which produces this effect.

The stimulus of hearing is the sound pressure in the ear, and loudness can, therefore, be measured by evaluating the air pressure in the ear. Although loudness is dependent upon the pressure, it is not directly proportional thereto, and the degree of pressure necessary to produce a stated degree of loudness varies with the pitch or frequency, of the sound. For a given note it is approximately proportional to the logarithm of the pressure, but only over a small range of frequencies. For this reason, and on account of the large range of audible sound pressures, the intensity of sound is generally expressed in decibels above a given reference level.

It may be noted here that decibels relate only to a power ratio or interval between two power quantities. Now, power is equal to energy passing per unit time, and decibels $= 10 \log_{10} \left(\frac{I_1}{I_2}\right)$

SYMBOLS.

I = energy intensity.
P = pressure.
D = distance of source of sound.
V = volume of room.
S = Sabine unit of absorption.
db = decibel
c = velocity of sound in air (ft/sec.)
ρ = density of air.

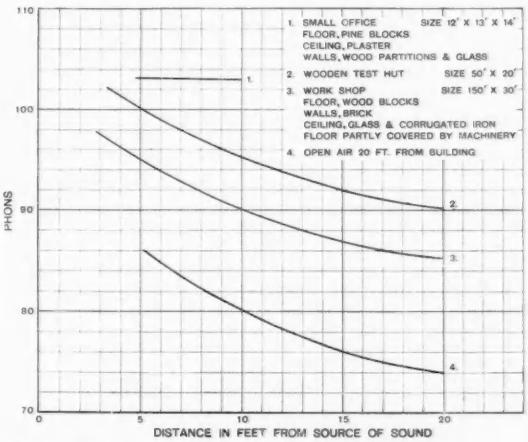

Fig. 2.—Curves showing sound measurements of the same piece of apparatus recorded in different types of building.

Where I_1 = energy passing.
I_2 = energy at reference level.

Now if P_1 and P_2 are the two sound pressures, then since, in a free progressive wave, energy flow

is proportional to the square of the pressure, power ratio is proportional to $\left(\frac{P_1}{P_2}\right)^2$

Hence db $= 10 \log_{10} \left(\frac{P_1}{P_2}\right)^2 = 20 \log_{10} \left(\frac{P_1}{P_2}\right)$

The "amount" of sound at a given point in a free progressive wave may be expressed as sound intensity, *i.e.*, energy passing per unit area (ergs/sec/cm^2).

For other distributions of sound, the sound intensity may in general be understood to be given by the relation $I = \frac{P^2}{\rho c}$

It may also be expressed as sound energy density, *i.e.*, energy per unit volume (ergs/cm^3).

The phon is a unit of equivalent loudness. A sound is said to have an equivalent loudness of n phons when the intensity of an equally loud standard tone is n decibels above a standard reference intensity. The standard tone adopted by the British Standards Institution is a plane sinusoidal sound wave train of 1,000 cycles per second, and the reference level is that corresponding to an R.M.S. sound pressure of ·0002 dynes per cm^2.

The variation in pressure between a just audible noise and the maximum noise of the same note which can be called hearing is from 1 to a million, and the energy ratio 1 to a billion. The ear is much less sensitive to low notes than to high notes, when both are soft, while for loud notes the difference is negligible. A study of the relationship between pressure and loudness has been made by Fletcher and Munson and their results have recently been verified by other experimenters.

Curves as determined by these experimenters are given in fig. 3, the curved lines represent lines of equal loudness. It will be seen that, for a soft sound, the intensity for equal loudness increases enormously as the frequency drops. As the loudness increases the curves straighten out, until at 90 phons the curve is nearly level over a large range of frequencies. Above 90 phons the curvature is reversed. The consequence of this is that, while under the conditions of free space the attenuation of sound intensity follows the square law, the attenuation of loudness is further complicated by the variation in sensitivity of the ear for loud and soft sounds.

The loudness in phons may be found, when the intensity is known, by reference to the curves.

Let the sound energy, in free progressive wave, at a distance D from the source be I ergs per second per cm^2, then the energy at a distance D_2 will be $I\left(\frac{D_1}{D_2}\right)^2$

If N is the sound energy intensity in decibels at a distance D_1, then the sound intensity at a distance D_2 will be $\left(N + 20 \log_{10} \frac{D_1}{D_2}\right)$

For example, if it be assumed that $\frac{D_1}{D_2} = \frac{1}{2}$ and $\log_{10} \frac{1}{2} = \bar{1}\cdot 7$

then sound at distance $D_2 = (N - 6)$ db.

That is doubling the distance decreases the energy intensity by 6 db. The relation between pressure and energy is $I = \frac{P^2}{\rho c}$ and hence the pressure will attenuate in proportion to D.

The above relationship holds for the condition of free space only.

When sound measurements are made in an enclosed space, the results will be modified and the effect of the volume and the size and composition of the walls of a building in which sound measurements are taken will now be considered. Sound generated in an empty room will travel in all directions until it meets the boundaries, when it will be partly reflected and partly absorbed. The portion of sound reflected will travel back until it strikes the opposite wall, when it will again be partly absorbed and partly reflected and so on through numerous reflections. At each reflection, the amount reflected is diminished by the amount absorbed. Each reflection may be regarded as a new source of sound, so that, if the generated sound is

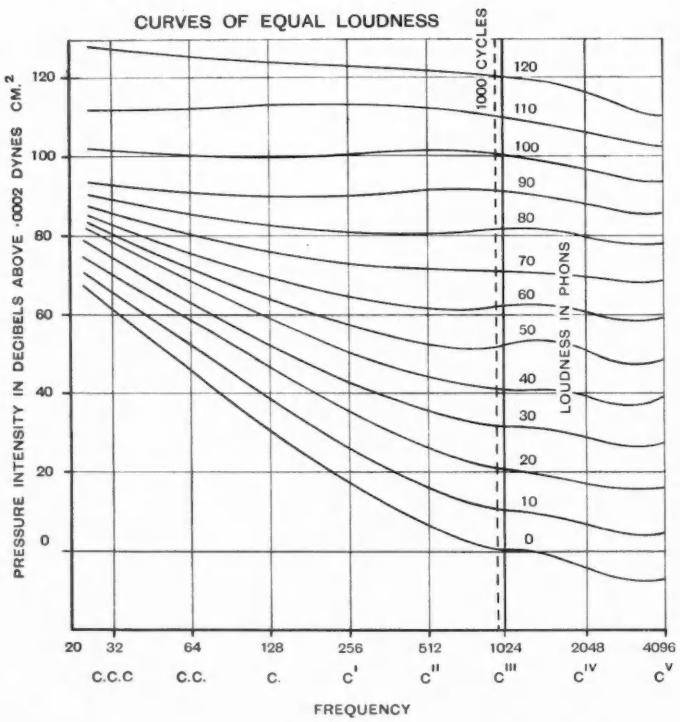

Fig. 3.—Curves showing relationship between pressure and loudness. (Fletcher & Munson).

continuous, the energy in the air will gradually increase by the addition of more and more reflections until a maximum is reached. This maximum will occur when the total loss of sound by absorption is equal to the amount generated. When the absorption is small the room will become "filled with sound," that is, the sound will be completely diffused, and will appear at approximately the same level at all points in the room. The increase in the sound due to this cause may be considerable as will be shown later on. The condition is analagous to a heater in an enclosed space: the heat generated travels in all directions until it is partly reflected and partly absorbed by the surrounding objects. The temperature of the air increases until the heat loss escaping into and beyond the walls is equal to the heat generated. The temperature of the air thus depends upon the heat properties and extent of the walls as well as upon the amount of heat generated.

In the case of sound the difficulty is increased by resonance of the mounting on which the machine is placed. The sound produced by a machine is chiefly caused by mechanically vibrating parts which communicate the motion to the air. In most cases the air slips round the moving part and only a small portion of the energy appears as sound. As a rule, the larger the surface the greater the noise produced by a given amplitude of vibration. Hence, if the machine is placed on a support which has a large area and is capable of taking up vibration by resonance, the noise produced will be greatly increased.

A boundary or obstruction is said to have one unit of absorption for a given frequency when the sound absorbed is equal to that which would flow away through unit area of free space. If the area is in square feet, the unit is the Sabine unit. Thus, if a chamber has S units of absorption, the loss of sound energy is equal to that which would flow away through a hole in the wall of S ft^2 area. The actual amount of sound energy absorbed by each Sabine unit will depend upon the sound energy density in contact with the absorbent area. When a continuously generated sound is present the level of sound at the absorbent areas will rise until the absorption equals the sound energy impinging on the area. Also if the sound energy is completely diffused, the sound will appear at approximately the same level at all points in the room. A table of acoustical absorption factors for various kinds of walls is given on this page. It will be seen that this figure varies with the frequency of the note as well as with the composition of the absorption surfaces. Different frequencies will therefore be affected unequally.

The number of Sabine units is found by multiplying the area of absorption in ft^2 by the appropriate acoustical absorption factor.

If a machine which generates several notes is examined in differently constructed chambers, it will be found that not only is the total noise varied, but also that the proportion of each constituent note is altered.

ACOUSTICAL ABSORPTION FACTORS.

Substance	Absorption of sound of pitch						
	CC	C	C^{I}	C^{II}	C^{III}	C^{IV}	C^{V}
Cyc.	64	128	256	512	1024	2048	4096
Wood blocks ¾″ pine laid in mastic ..	—	0.05	0.03	0.06	0.09	0.10	0.22
18″ brick wall, unpainted ..	0.021	0.024	0.025	0.031	0.042	0.049	0.07
18″ brick wall, painted	0.011	0.012	0.014	0.017	0.020	0.023	0.025
Gypsum plaster of hollow tiles ..	0.012	0.013	0.015	0.020	0.028	0.040	0.050
Lime plaster on laths	0.048	0.020	0.024	0.034	0.030	0.028	0.055
Do. painted ..	0.036	0.012	0.013	0.018	0.045	0.028	0.055
Canvas, 6″ from wall	—	0.01	0.12	0.25	0.33	0.15	0.35
Teak panelling, 3 ply, 1″ from wall	—	0.09	0.17	0.17	0.15	0.15	0.15

The acoustical reflection factor = 1 – absorption factor.

The period of reverberation of a building may be used to estimate the sound intensity within it, due to a known energy output of sound. It is defined as the time taken by the sound energy to fall to a millionth part of the original value.

The difference in intensity between a fairly loud sound and a just audible sound is approximately 1 to 1,000,000, so that the period of reverberation may also be defined as the time taken for a loud noise to fall into inaudibility. The period of reverberation of a room may be roughly measured by noting the time taken for a noise, such as a sharp hand clap, to die away. When the area and nature of the walls, floor and ceiling of an empty room are known, the period of reverberation for a given note can be estimated from tables of absorption for the various kinds of material used for the walls.

The period of reverberation of a room is given approximately by the expression $\frac{1}{20S}$

where V = volume of room in cubic feet.

S = number of Sabine units of absorption.

The expression is strictly applicable only to cases where the sound energy is completely diffused. However, it has been found to give a fairly close approximation for all except very non-reverberent rooms. If the expression $\frac{V}{20S}$ is divided by V the quotient is $\frac{1}{20S}$, which is proportional to the reciprocal of S; hence from what has been said above, it is evident that the sound energy density in a reverberent room, caused by a source of sound of given output, is directly proportional to the time of reverberation divided by the volume of the room.

As has already been pointed out, the absorption varies with the frequency of the note as well as with

the nature of the substance of the walls, and hence the time of reverberation differs for each note. The result is that if a constant source of sound, such as a motor, is placed in buildings having different sound properties, not only is the level of noise varied, but the level of the individual notes composing the sound is altered in different proportions.

The important point which emerges from these considerations is that a true comparison of different sound measurements is only possible if an exact description is given of the condition of the environment. For this reason, a standardized room of special construction is necessary when comparative tests of noise are required.

THE SOUND MEASUREMENT ROOM.

There are two essentials in a room to be used for sound measurements.

1. It must exclude all extraneous noises, so that the inside is perfectly quiet.
2. The walls must be highly absorbent so as to preclude reflections.

The principal ways by which sound enters a chamber from outside are :—

1. Air borne through holes or chinks in the walls.
2. Extraneous air-borne noise impinging on the walls and causing them to vibrate, thus communicating the vibration to the air inside the room.
3. Sound vibration communicated through the ground or supports, and re-radiated to the air inside the chamber.

No. 1 is met by building a room without any opening to the outside, the necessary doors being made airtight. A difficulty occurs, however, if ventilation is provided, and special means have been used in the G.E.C. sound measurement room to achieve this without allowing sound to enter through the ventilating ducts.

No. 2 is best countered by massive walls.

No. 3 can be prevented by the use of specially resilient supports.

The G.E.C. sound measurement room is shown in fig. 5, and a sectional arrangement in fig. 4.

The building is 14ft long, 14ft. deep and 12ft. high inside, and is flexibly supported on rubber blocks resting on solid concrete foundations. The floor is constructed of reinforced concrete on which are carried the brick walls, which are 14 inches thick. The roof is also of reinforced concrete 14 inches thick, and the total weight of the building is 80 tons. The whole structure is sufficiently braced together so that it can be jacked up in order that the rubber blocks may be replaced when necessary. Double sound-proof doors of 2-inch teak are provided, one set opening inwards and the other set outwards. An overhead runner with travelling lifting gear is provided for placing heavy machines in position.

The building being airtight, some mode of ventilation is necessary in view of the fact that some tests may require considerable time. The ordinary means of ventilation being unsuitable for a sound measurement room, however, a novel method has been adopted which

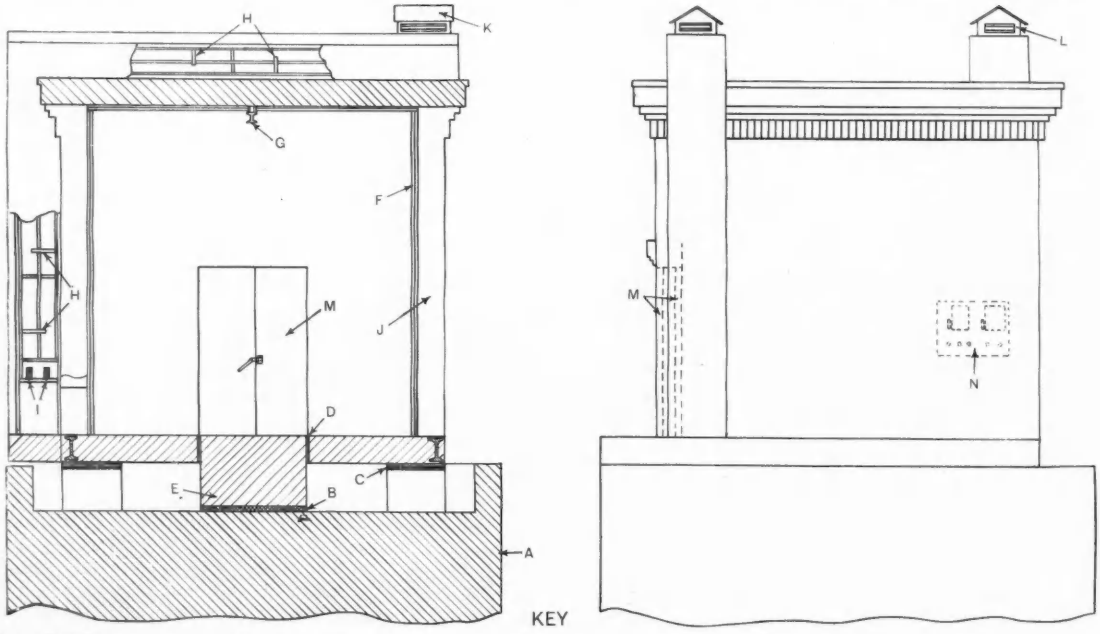

Fig. 4.—Sectional drawing of the sound measurement building.

provides ample ventilation without interfering in any way with the sound properties of the building.

Two ventilating ducts are provided: the intake duct leads from an aperture in the ceiling at one corner and runs the length of the roof to an inlet formed by a short chimney with louvre openings; the outlet duct, which is built in the wall, starts from an opening at ground level at the diagonally opposite corner of the building, and also runs along the roof to a similar short chimney. By this means, long lengths of ducts are provided with right angle turns. To prevent the entrance of air-borne noise, both ducts contain a number of special asbestos baffles $\frac{3}{4}$in. thick arranged at right angles to the ducts, the baffles leaving openings alternately at top and bottom so as to form a zig-zag passage for the air paths. In addition, the ducts are lined with asbestos blankets, and both the blankets and baffles are of highly sound-absorbent material. The whole of the baffle structure is built on a centre core, so that the arrangement can be withdrawn in one unit should this be necessary.

Ventilation through the ducts is obtained by means of a 2 kW heater placed in the outlet duct just above the floor level opening. The air in the vertical duct is heated and tends to rise, thus drawing in fresh air through the other duct. When using a 2 kW heating unit it is found that the air in the building is entirely changed every 10 minutes.

Figs. 1 and 6 show the inside of the building with machines of different sizes undergoing tests. The switchboard is shown on the rear wall, while the inlet ventilating duct can be seen at the top left hand corner.

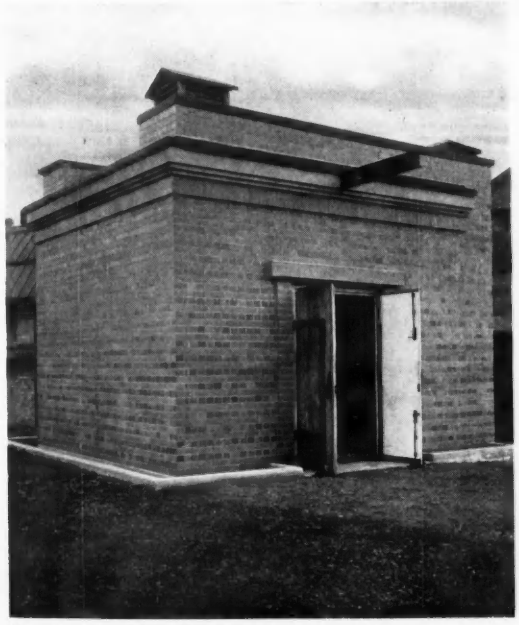

Fig. 5.—Exterior of the G.E.C. sound measurement building with the doors open. The entrance to the ventilation ducts can be seen on the roof.

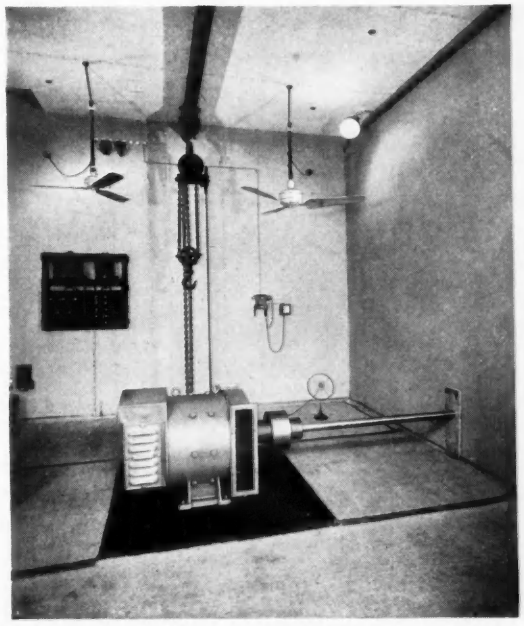

Fig. 6.—50 h.p. motor in readiness for noise testing in the sound measurement building.

The building is lighted by means of four corner lights, and for the operation of equipment under test five separate supplies of current are brought in through porcelain tubes built into the walls; provision has also been made for extra supplies when required. The switchboards shown in figs. 1 and 6 are made as small as is practicable so as to keep reflecting surfaces to a minimum. A solid concrete block rises through the floor but is not in contact with it, and on this block are mounted the various machines to be tested. Special flexible jointing material is used to fill the space between the block and the surround of the floor so as to exclude the entrance of air-borne sound and also to avoid rigid contact between the block and the floor. The concrete block is also separated from the foundations by being mounted on india rubber pads in the same way as the main building. The interior walls and the ceiling are lined with special absorbent material spaced away from the walls, and the floor is covered with matting.

The building is now in regular use for measuring the different types of sound commonly associated with electrical machinery, and the acoustic properties described make possible sound measurements which are not only consistent among themselves, but have a more definite absolute significance than it would be possible to achieve by any other means.

Instruments Incorporating Thermionic Valves, and their Characteristics.

PART I.

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This article is reprinted from a paper read before the Meter and Instrument Section of the Institution of Electrical Engineers on the 6th January, 1939. In Part I. the authors discuss the main characteristics of valves which are used in various types of instrument, with particular reference to those valves which have been specially designed for measurement purposes, and the different types of A.C. valve voltmeter employing vacuum and gas-filled tubes are described.

INTRODUCTION.

THE thermionic valve has long been recognized as a useful tool in almost every branch of science and engineering; but, although experimenters have realised the possibility of using valves for measurement purposes, engineers have until recently, and not without some justification, regarded the valve as being rather an unknown factor, and have been reluctant to rely on such devices for precision measurements.

During the past few years, however, several instrument makers have put on the market instruments incorporating thermionic valves which are capable of satisfying the two important requirements, accuracy and reliability. This has been made possible, on the one hand, by the instrument makers, who have designed apparatus in such a manner that variations in valve characteristics and supply voltages are automatically compensated, and, on the other hand, by the enormous improvements both in uniformity and stability of valve characteristics which have been effected in recent years. Furthermore, the progressive valve manufacturer of to-day not only produces valves on a mass production basis for radio communication, but is also aware of other applications and supplies valves having the particular characteristics necessary for various types of instrument.

It is not proposed to describe in this article all the possible methods of using valves for measurement purposes, or to consider the design of amplifiers and oscillators which are frequently used in conjunction with measuring instruments. The authors have limited the scope of the article to include those instruments in which the thermionic valve is an essential component and which either provide the only means of carrying out a particular measurement or possess definite advantages over alternative forms of instrument.

VALVE CHARACTERISTICS.

The factors in a valve which may be of importance in determining the characteristics of an instrument are (a) the relationship between the output current and input voltage, (b) the input impedance and (c) stability of characteristics.

(a) Output-Current / Input-Voltage Characteristics.

The shape of the curve relating anode current to anode voltage of a diode is shown in fig. 1.

The "tail," *AB*, of the characteristic, obtained

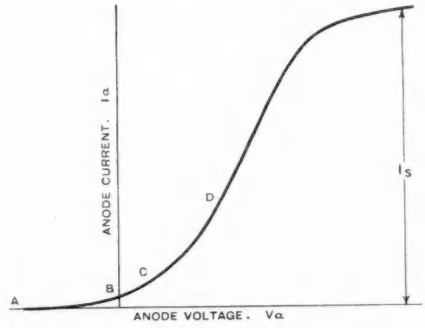

Fig. 1.—Anode current—anode voltage characteristic of a diode.

when the anode is at a sufficiently negative potential to the cathode, is exponential and obeys the equation

$$I_a = I_s \varepsilon^{e(V_a + v)/kT}$$
$$= I_s \varepsilon^{K(V_a + v)} \quad - - - - - - (1)$$

where I_s is the total emission of the cathode in amps.

V_a is the voltage of the anode relative to the cathode.

v is the contact potential difference between anode and cathode.

e is the electronic charge. $(1{\cdot}59\times10^{-19}$ coulombs).

κ is Boltzmann's constant. $(1{\cdot}37\times10^{-23}$ joules/degree).

T is the absolute temperature of the cathode

and $K = \dfrac{e}{\kappa T} = \dfrac{11{,}600}{T}$

Over the portion CD of the curve, the current obeys the space charge law $I_a = A\ (V_a + v)^{3/2}$ where A is a constant depending on the geometry of the electrode system.

At some part of the curve between B and C, the curve is approximately parabolic, while beyond D the curve becomes linear and then bends over to the saturation value of the current, I_s.

The general shape of the anode-current/grid-voltage characteristics of triodes, tetrodes and pentodes is similar to the diode characteristic but displaced relative to the axis $V_g = 0$ by an amount depending on the anode or screen potentials and the constants of the valve.

Use is made of the exponential characteristic in slide-back voltmeters, grid-leak voltmeters and in logarithmic voltmeters, while the square law characteristic is important in the design of anode bend voltmeters, wattmeters and harmonic analysers.

The range over which the various relationships—exponential, parabolic, etc.—hold, depends on the geometry of the electrodes. Thus the smaller the distance between anode and cathode of a diode, or between grid and cathode in the case of triodes, tetrodes and pentodes, the greater will be the value of current below which the curve is exponential. From equation (1) it follows that, if $\log_\varepsilon I_a$ is plotted against V_a, the curve will be a straight line with a slope $K = \dfrac{e}{\kappa T}$. The normal operating temperature of a modern oxide coated cathode is approximately 1000°K so that the theoretical value of K is 11·6. Fig. 2 shows $\log_{10} I_a$ plotted against V_a for the diode type D63 and it will be seen that the exponential characteristic holds for currents up to 20 microamps, the actual value of K, deduced from this line, being 11·0, which is in close agreement with the theoretical

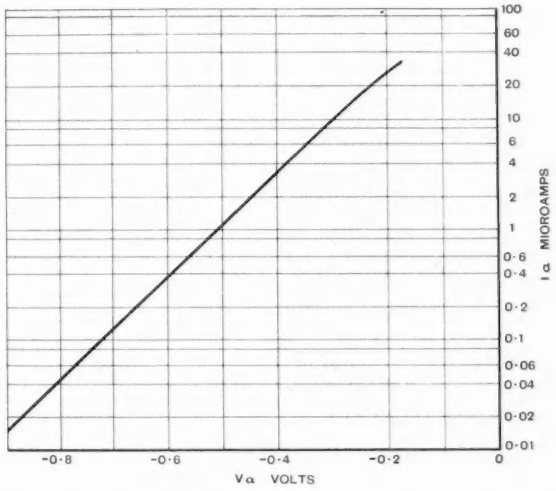

Fig. 2.—Anode current—anode voltage characteristic of diode D.63.

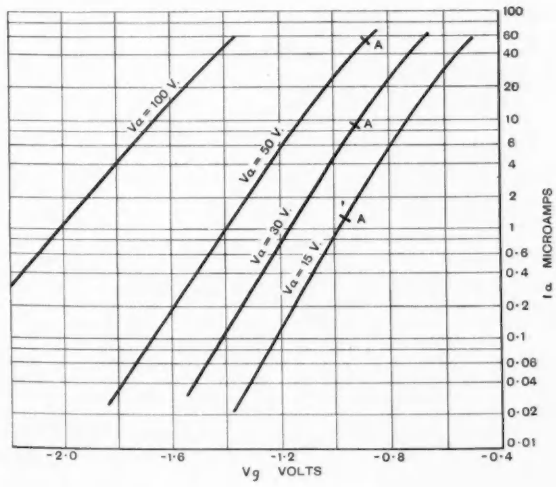

Fig. 3.—Anode current—grid voltage characteristics of triode H.63.

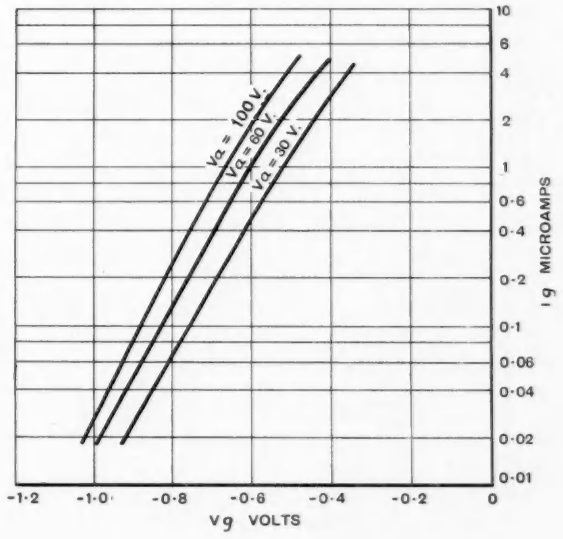

Fig. 4.—Grid current—grid voltage characteristics of triode H.63.

value. Fig. 3 shows the anode-current/grid-voltage characteristics of a triode, type H63, for anode voltages between 15 and 100 volts. The pitch of the grid winding and the grid-cathode distance are small in this triode, and it will be seen that the curves are exponential up to currents of about 10 microamps, but that the value of K decreases from 9·6 at $V_a = 15$ volts to 6·3 at $V_a = 100$ volts. This decrease is due to the field near the cathode becoming less uniform as the anode potential is increased and would be even more noticeable in a valve with a lower amplification factor. The grid-current/grid-voltage characteristic for the H63 type is shown in fig. 4; the curve is exponential up to about 1 microamp and here again the value of K decreases as the anode voltage is increased.

The above "retarding-field" exponential characteristics were obtained with a valve in which the grid pitch was uniform over its entire length. The grid can, however, be wound with a variable-pitch such that the anode-current/grid-voltage characteristic is approximately exponential for a large range of grid bias, *i.e.*,

$$I_a = B\varepsilon^{bV_g}$$

and the mutual conductance $g_m = \frac{\delta I_a}{\delta V_g} = Bb\varepsilon^{bV_g}$.

Fig. 5 shows the anode-current, I_a, and mutual conductance, g_m, plotted against grid bias for a W63 valve. The curves are approximately exponential for values of bias above 5 volts.

The range over which the anode current characteristic is parabolic is very limited in diodes and in triodes having close wound grids, but with valves in which the grid pitch is large, generally valves with low amplification factor, the range may be quite considerable, particularly when the valve is operated at high anode voltages. This is probably due to the fact that in such valves the grid is not only exercising space charge control at the cathode surface but is also, over this part of the characteristic, acting as a shutter and limiting the area of the cathode from which electrons are escaping. This point is illustrated in figs. 6–8.

Figs. 6 and 7 show the mutual conductance, g_m, plotted as a function of grid bias for the types

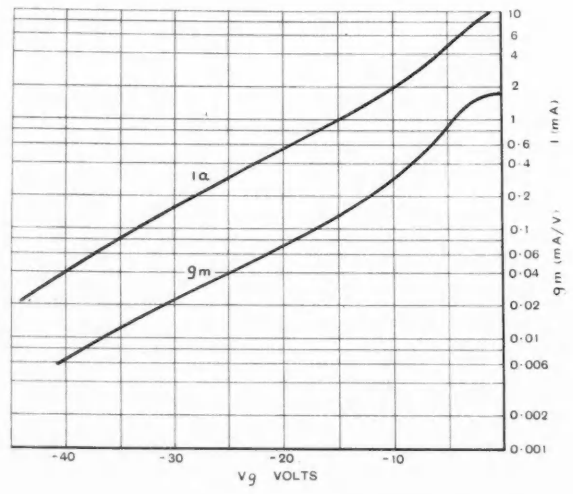

Fig. 5.—Anode current—grid voltage and mutual conductance—grid voltage characteristics of pentode W.63.

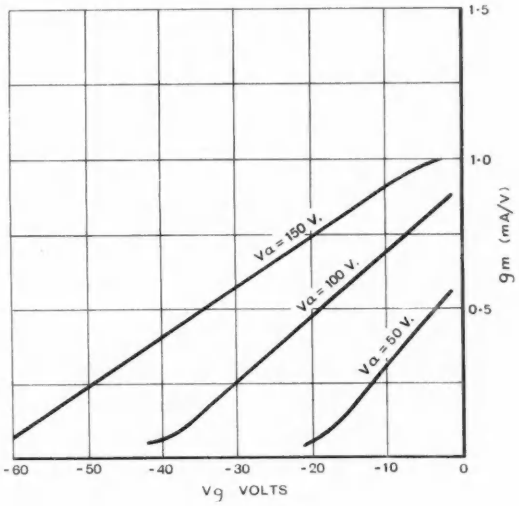

Fig. 6.—Mutual conductance—grid voltage characteristics for triode L.S. 5A ($\mu = 2.5$).

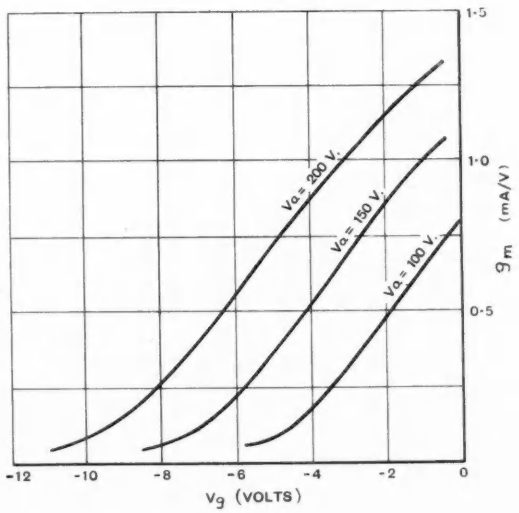

Fig. 7.—Mutual conductance—grid voltage characteristics for triode L.S. 5B ($\mu = 20$).

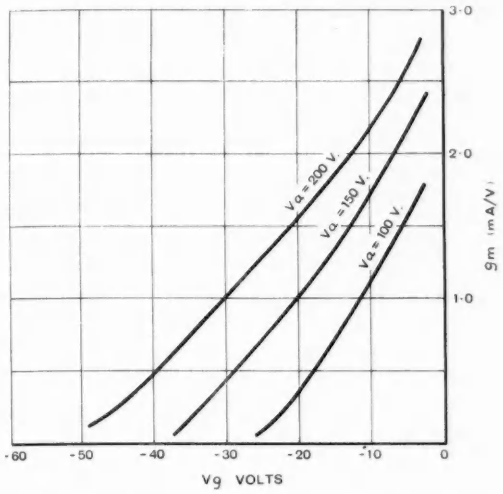

Fig. 8.—Mutual conductance—grid voltage characteristics for triode A.577 ($\mu = 6$).

LS.5A, and LS.5B, which are two triodes of similar design except for the grid pitches which are 3·65 mm. and 1·06 mm. respectively, giving amplification factors of 2·5 and 20. It will be seen that the range of g_m over which the $g_m - E_g$ relationship is linear, and therefore $I_a - E_g$ parabolic, is greater in the valve with low amplification factor and at high values of anode voltage. Fig 8 shows similar curves for the type A577 (designed for use in valve voltmeters, $\mu = 6$) which has an indirectly heated cathode.

(b) Input Impedance.

The factors affecting the input impedance of a valve are electron and ion convection currents in the grid circuit, the capacitance between the grid and other electrodes and, at very high frequencies, the inductance of the leads to the electrodes and the finite transit time of electrons between the electrodes.

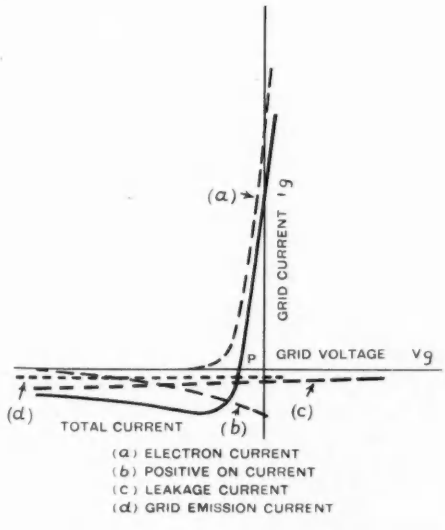

Fig. 9.—Grid current—grid voltage characteristics of a triode.

The static grid-current/grid-voltage curve for a triode is itself the sum of several curves due to different causes, chief amongst which are (a) the electron current from cathode to grid, which has been mentioned earlier and which is an exponential function of the grid voltage under normal operating conditions, (b) positive ion current due to residual gas in the valve, (c) leakage currents across insulators separating the electrodes and (d) emission of primary electrons from the grid. Fig. 9 shows the shape of the current/voltage curves due to these causes together with the resultant grid current characteristic. In the type of valve likely to be used for instrument purposes the maximum negative grid current is usually less than 0·1 microamp and the insulation resistance exceeds 10^9 ohms.

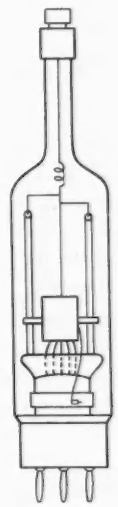

Fig. 10.—The electrometer triode.

Although the grid current in standard valves when the grid is negative to the cathode is sufficiently low for most measurement purposes, considerably lower values are necessary when it is desired to use the valve as an electrometer. By special choice and design of the supporting members of the grid and by operating the anode at a potential considerably lower than the ionisation potential of any residual gas, it has been possible to eliminate almost entirely the leakage and ionisation currents. Other factors which may contribute to the grid current, such as ions from cathode and anode and photoelectrons from the grid have been reduced to a minimum by suitable choice of electrode materials and by operating the valve in the dark. Valves of this type have been described by Metcalfe and Thompson[1] and by Warren[2], and in fig. 10 is shown a drawing of one type of electrometer triode. Typical anode current and grid current characteristics are shown in fig. 11.

Low input capacitance is important in some electrostatic measurements, and in the case of the electrometer triode, mentioned above, its value is 2 micro-microfarads.

In A.C. measurements the input capacitance must be small in order that its impedance may be large in comparison with that of the source. In

standard types of valves this capacitance is about 10 micro-microfarads.

When the frequency of the voltage to be measured is very high, the inductance of the connection between the source and the electrodes may have appreciable reactance. This inductance forms a series circuit with the input capacitance, so that the voltage across the electrodes may be considerably higher than that of the source. For the error to be less than 0·1 per cent, the operating frequency must not exceed about 3 per cent of the resonant frequency of this series circuit, or for 1 per cent error about 10 per cent of the resonant frequency.[3,4] Since the length of the connecting leads cannot be reduced indefinitely, the maximum frequency at which a voltmeter can be used with any accuracy is determined by the smallness of the valve input capacitance. The diode offers the greatest possibility of low input capacitance, and, in the type A.373, shown in fig. 12a, this has been reduced to 0·4 micro-microfarad and the leads are as short as possible. The impedance error with this diode is about 1 per cent at 100 megacycles/sec. In valves of the "Acorn" type (fig. 12b) the input capacitance is about 3 micro-microfarads and the impedance error at the same frequency is about 4 per cent.

Type.	Mutual Conductance.	Input Resistance.
KTW63	1.5 mA./V.	13,000 ohms.
KTZ41	7.5 mA./V.	2,000 ohms.
ZA1	1.4 mA./V.	50,000 ohms.

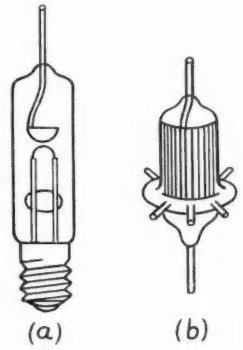

Fig. 12.—Type A.373 and "acorn" type valves.

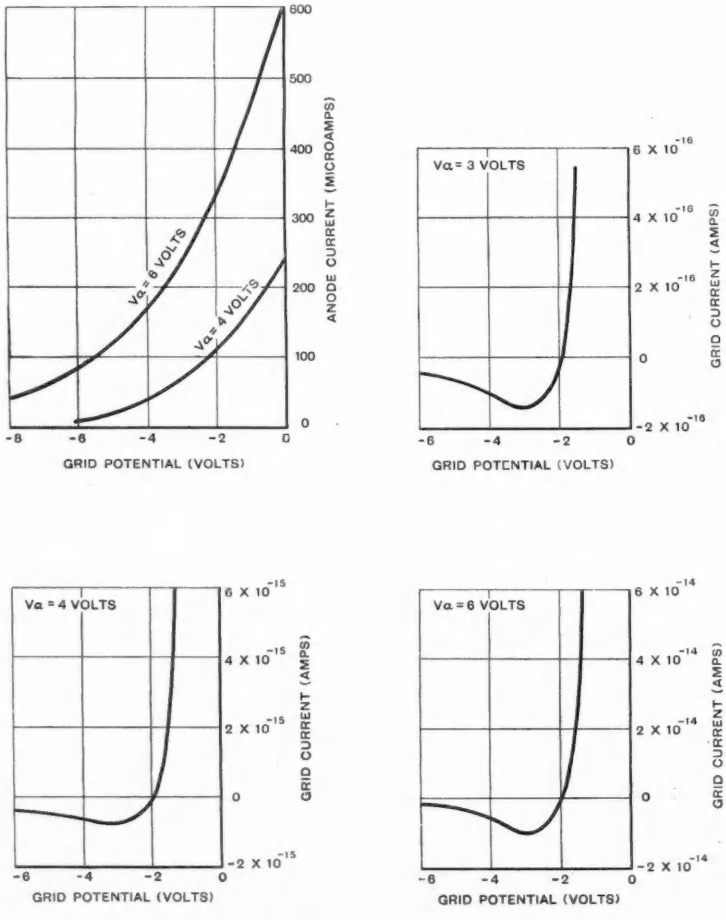

Fig. 11.—Typical anode current and grid current characteristics of an electrometer triode.

Dielectric losses in the input capacitance of a valve will affect the power consumed from the source, but of far greater importance at very high frequencies are effects arising from the physical size of the valve. If the transit time between cathode and grid and between grid and anode become comparable with the period of the H.F. voltage, the current will not vary in phase with the grid voltage and appreciable power will be absorbed from the source. Power will also be absorbed due to coupling inside the valve, between the input and output circuits: this effect depends on the size of the inter-electrode capacitances and on lead lengths.

In the "Acorn" type of valve the smallness of the structure reduces the transit time, inter-electrode capacitances and lead inductances to a minimum, so that the valve is very suitable for use in high frequency voltmeters. The above table gives the values of the input resistance of various types of valves at 40 Mc./sec.

(c) *Stability of Characteristics.*

Although uniformity between characteristics of valves of the same type may not be as good as the

instrument maker might wish, the modern valve gives a very stable performance during its life, particularly under the operating conditions imposed in measuring devices. The valve manufacturer usually subjects valves required for this purpose to a long ageing treatment, often as much as 100 hours, in order to stabilise the cathode emission and the contact potential differences between electrodes, since any drift in characteristics due to these factors is likely to be greater during the first few hours of operation than subsequently.

The stable operation of a device employing a thermionic valve depends not only on the stability of the valve characteristics but also on the constancy of the applied voltages. In the case of an amplifier, any changes in gain due to changes in the valve characteristics or in the applied voltages can be reduced to a large extent by applying negative feedback to the amplifier valves.

The principle of feedback is illustrated in fig. 13, which shows a schematic diagram of an amplifier, in which a fraction, β, of the output is connected in series with the input.

If M = amplifier gain without feedback,
M_1 = amplifier gain with feedback,
E_2 = output,
E_o = the input without feedback
and E_1 = the input with feedback to give the same output,

$$\text{then } M = \frac{E_2}{E_o}$$

$$\text{and } M_1 = \frac{E_2}{E_1} = \frac{E_2}{E_o + \beta E_2} = \frac{M}{1 + M\beta}$$

i.e., the gain of the amplifier with feedback is reduced in the ratio $\frac{1}{1 + M\beta}$.

Any variation in the valve characteristics, or variations in the applied voltages, will give rise to a change in the amplification. Let δM be the change in gain due to any of the above causes without feedback and δM_1 the corresponding change with feedback; then[5]

$$\frac{\delta M_1}{M_1} = \frac{\frac{\delta M}{M}}{1 + M\beta}$$

That is, the percentage change in the amplification is reduced by an amount corresponding to the reduction in the amplification. If $\frac{1}{M} \ll \beta$, the gain $M_1 \doteqdot \frac{1}{\beta}$, *i.e.*, the amplification is almost entirely independent of the circuit.

Feedback can be applied to an amplifier in various ways. The simplest method, and that usually adopted in instruments, is to include a resistance in the cathode lead of the valve. Examples are found later in this article.

ALTERNATING CURRENT VOLTMETERS.

Of all valve measuring devices, the valve voltmeter seems to be the most widely used instrument, especially for high frequency measurements. Its popularity lies in the fact that it is sensitive, and that it can be designed to absorb negligible power from the source. The type of voltmeter to be used in any particular case depends on the wave-form of the voltage, on the value required (peak or R.M.S.) and on the frequency at which the measurement has to be made.

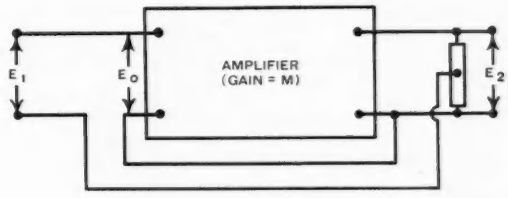

Fig. 13.—Schematic diagram of degenerative amplifier.

All A.C. voltmeters are essentially rectifiers, and in the following description have been classified according to the method of rectification.

(*a*) (i) *"Slide-Back" Type using Hard Valves.*

The simplest type of valve voltmeter is the "slide-back" type, in which a triode or other multi-electrode valve is used as a threshold indicator. The valve is biased until the anode current is very small and the bias is measured by a D.C. voltmeter. The alternating voltage to be measured is then applied to the grid of the valve, in series with the bias voltage, and the bias increased until the current is reduced to its original value. The difference in the two readings of the D.C. voltmeter gives a measure of the peak value of the alternating voltage: the exact relationship may be determined by a study of the valve characteristic.

With small currents, the anode-current/grid-voltage characteristic for a triode with a close wound grid is given by

$$I_a = B\varepsilon^{KV_g}$$

If a sinusoidal voltage, $E \cos \omega t$ is applied to the grid, the anode current will be given by

$$I_a = B\varepsilon^{K(V_g + E\cos\omega t)}$$

It can be shown[6] that, if V_1 is the grid bias necessary to give a definite anode current with no alternating

voltage applied to the grid, and V_2 the bias to give the same current when an alternating voltage of amplitude E is applied, then

$$\frac{V_2 - V_1}{E} = \frac{1}{KE} \log_e I_o(KE) = f(KE)$$

where I_o is the zero order modified Bessel function of the first kind.

For any value of E, $f(KE)$ can be calculated if K is known, so that the ratio $\frac{V_2 - V_1}{E}$ can be determined. The calculated value of the ratio $\frac{V_2 - V_1}{E}$ is plotted against KE in fig. 14. It will be seen that for values of KE above 100, the error in assuming $V_2 - V_1 = E$ is less than 3 per cent, but for small values of KE the error is very considerable. For example if $K = 10$, and $E = 0{\cdot}2$ volt, the error in assuming $V_2 - V_1 = E$ is more than 50 per cent.

The theory shows that, as long as the characteristic is exponential, the value of the anode current is immaterial, and this is borne out approximately in practice. The various points in fig. 14 are experimentally determined, using an H63 Triode with $V_a = 30$ volts, and show the ratio $\frac{V_2 - V_1}{E}$ against KE for $I_a = 0{\cdot}5\,\mu A$, $1{\cdot}0\,\mu A$ and $5{\cdot}0\,\mu A$. The points do not exactly coincide, due presumably to the value of K being slightly higher at the lower anode currents.

If the value of K for the valve is known, the calibration can be calculated for the slide-back voltmeter and the instrument can then be used for the measurement of peak voltages down to about 0·2 volt with a fair accuracy. The calculated calibration is only accurate for sinusoidal voltages, and the ratio $\frac{V_2 - V_1}{E}$ for a non-sinusoidal voltage would depend on the wave-form.

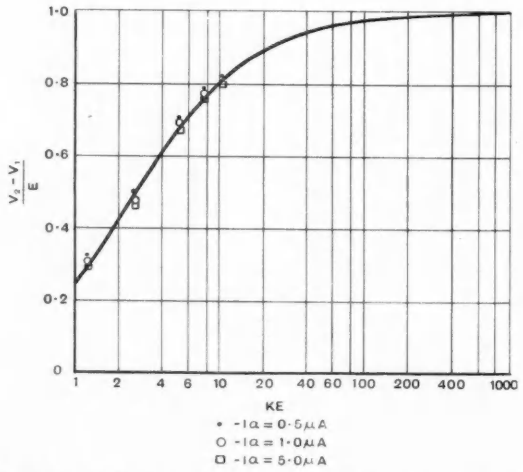

Fig. 14.—Ratio of apparent peak voltage, $V_2 - V_1$ to the direct peak voltage E, as a function of KE.

The points marked "A" on the curves of fig. 3 show the values of the grid bias and anode current for 0·1 μA grid current. For the same grid current, the anode current is much larger with $V_a = 30$ volts than with $V_a = 15$ volts, so that although the value of K is slightly smaller for $V_a = 30$ volts, the grid current is lower and therefore the input resistance is higher.

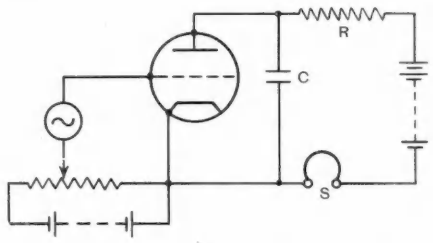

Fig. 15.—Gas-filled relay as slide-back voltmeter.

(ii) *Slide-Back Type using Gas-filled triodes.*

The introduction of a gas such as mercury or argon into a triode valve makes it very suitable for use as a slide-back voltmeter. Such a valve passes no anode current if the grid potential is more negative than a certain value, while at a smaller value of grid potential gas discharge takes place and the current increases rapidly. This critical value of grid potential depends on the anode voltage and is very sharply defined.

In order to measure the peak value of an alternating voltage, the grid bias is adjusted to its critical value and the A.C. voltage superimposed on the grid. The bias is again adjusted to its critical value and the difference in the two D.C. readings gives the peak value of the alternating voltage.

The critical grid voltage can be adjusted by observing when the discharge takes place in the valve or by observing the current in a meter in the anode circuit. Both of these methods suffer from the disadvantage that the anode voltage has to be switched off, once the arc has been formed, as the grid has then no controlling action on the anode current. This disadvantage can be overcome by the use of a resistance-capacitance combination in the anode circuit of the valve, so that the anode voltage falls periodically to zero[7]. The circuit is shown in fig. 15. The condenser C is charged by the battery through a resistance R, and when it attains a sufficient potential it discharges through the valve, producing a click in the phone S. The critical bias is indicated by a slow clicking in the phone; on one side there is silence, while on the other the clicking merges rapidly into a buzzing sound. The critical potential, with and without the alternating voltage, can therefore

be determined accurately without any need of switching-off the anode voltage. Using a GT1C gas-filled relay, the difference in the bias voltages was found to be equal to the peak value of the alternating voltage to an accuracy of about 3 per cent down to 0·5 volt, the accuracy increasing as the peak

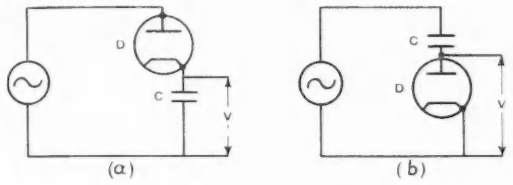

Fig. 16.—Diode peak voltmeter.

voltage increased; the error for the same peak voltage using a hard triode is about 35 per cent. The disadvantages in using a gas-filled triode are: (1) the highest potential that can be measured is limited by the potential at which cold discharge takes place between grid and cathode; (2) the critical grid voltage depends on the temperature of the gas; an argon-filled valve is therefore preferable to mercury-filled; (3) the ionisation time is about 10 micro-seconds while the de-ionisation time may vary between 10 and 1000 micro-seconds, according to the design, temperature and operating conditions, (4) when the negative grid bias is greater than the critical potential, the grid current is negligible, but at the critical point it can become quite appreciable. The instrument will, therefore, absorb power from the source, and in this respect is inferior to the hard valve.

(b) Peak Voltmeters using Diodes.

One of the most convenient methods of measuring peak voltage, especially at very high frequencies, is to charge a condenser through a diode as in fig. 16 (a) and (b). When equilibrium is reached, the D.C. voltage V is, in the ideal case, equal to the peak value of the alternating voltage. In practice, V is approximately equal to the peak value for voltages above 10 volts, but for lower voltages errors occur due to the initial velocity of the electrons.

For very small currents, the anode-current/anode-voltage characteristic of a diode is exponential, so that if no other conducting path existed between cathode and anode, the condenser would eventually charge up to an infinite potential. However, there is always a finite resistance across both valve and condenser, so that the condenser voltage reaches a steady value at which the initial velocity current is balanced by the leakage current.

If the effective resistance across the valve and condenser is R and I_1 is the direct current through the resistance with no alternating voltage applied, then the condenser voltage V will be $-RI_1$.

The electron current through the valve is given by

$$I_1 = I_s \varepsilon^{KV}$$

Hence $I_s \varepsilon^{KV} = -\dfrac{V}{R}$

If an alternating voltage $E \cos \omega t$ is now applied to the system, the direct current through the resistance will increase to I_2, and the voltage across the diode will be given by

$$V_a = E \cos \omega t - RI_2$$

The anode current will therefore be given by

$$I_a = I_s \varepsilon^{KE \cos \omega t} \varepsilon^{-KRI_2}$$

This equation has been treated by Colebrook[8] and

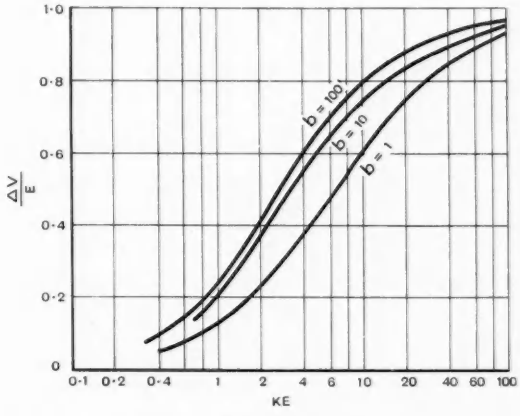

Fig. 17.—Efficiency of rectification as a function of KE $b = KRI_1$, where I_1 = the "no signal" diode current.

lately by Aiken.[9] Reference to these papers shows that the quantity $\varepsilon^{KE \cos \omega t}$ can be expressed in the form

$$\varepsilon^{KE \cos \omega t} = \mathrm{I}_o(KE) + 2\sum_{n=o}^{n=\infty} \mathrm{I}_n(KE) \cos n\omega t$$

Therefore the steady part of the current is

$$I_2 = I_s \, \mathrm{I}_o(KE) \, \varepsilon^{-KRI_2}$$

The rectified voltage is equal to the change in the voltage drop across the resistance R when the voltage E is applied. If this change is ΔV, then

$$\Delta V = R(I_2 - I_1) = RI_1 [\mathrm{I}_o(KE)\varepsilon^{-K\Delta V} - 1]$$

or $\varepsilon^{K\Delta V}[K\Delta V + b] = b\mathrm{I}_o(KE)$

where $b = KRI_1$

i.e., the rectified voltage is given in terms of the resistance R, the "no signal" current I_1, the constant K and the input voltage E.

When R is fixed, I_1 is a constant, so that ΔV can be calculated for any value of E. Aiken shows curves connecting $\frac{\Delta V}{E}$ with KE for various values of b and for the sake of clearness, these curves are reproduced in fig. 17.

The rectification efficiency $\frac{\Delta V}{E}$ increases both with K and b, but it is shown that very little improvement is obtained if b is increased beyond 100. With a normal diode, the resistance R is generally of the order of 1000 megohms, and b would lie between 10 and 20. With this value of R and $K = 10$, $\frac{\Delta V}{E}$ would be equal to 0·95 for a peak voltage of 10 volts, the error decreasing as the peak voltage is increased. At $E = 100$ volts the error would be negligible.

It is important that the capacitance C should be large in comparison with the diode capacitance, so that all the alternating voltage appears across the diode. However, C should not be made unnecessarily large, in order to keep the charging current down to a negligible figure, so that a diode with small electron emission, giving long life and small dimensions, can be used.

If the transit time of the electrons between cathode and anode is comparable with the period of the applied voltage, some electrons will fail to reach the anode before the electric field in the diode reverses. The voltmeter will therefore read low at very high frequencies and it has been shown[3, 4] that the error is approximately proportional to the frequency, f, and to the cathode-anode distance, d, and inversely proportional to the square root of the applied voltage E. For this error to be less than 1 per cent, the ratio $\frac{fd}{\sqrt{E}}$ must be less than 0·1 when f is in Mc./sec, d in cm. and E in volts.

The voltage across the condenser can be measured conveniently by means of an electrostatic voltmeter, and the method has the advantage that the resistance can be kept very high. However, it has the disadvantage that the reading of the voltmeter does not follow variations in the voltage to be measured. A resistance of the order of 10 to 50 megohms is therefore often connected across the condenser, but this resistance must be kept large so that the condenser voltage does not drop appreciably during a cycle of the applied voltage[10].

An alternative and convenient method of measuring the condenser voltage is as shown in fig. 18[11]. The D.C. rectified voltage is applied to the grid of a triode valve, which has a high resistance R in series with the cathode. The condenser C_1 and resistance R_2 serve as a filter for the H.F. voltage, while the resistance R gives rise to negative feedback in the triode. Then the change in anode current δI_a for a change δV_g in grid voltage is given by

$$\delta I_a = \frac{\mu}{r_a + R(1+\mu)} \delta V_g$$

where μ = amplification factor and r_a = anode A.C. resistance of the valve. If $R(1+\mu)$ is large in comparison with r_a and $\mu >> 1$ (for a valve such as the H63, $\mu = 100$)

$$\frac{\delta I_a}{\delta V_g} \doteq \frac{1}{R},$$

that is, the change in anode current is approximately proportional to the change in grid voltage, while the sensitivity can be changed by altering the value of R. As the sensitivity is determined only by the resistance R, large variations in the valve characteristics and supply voltages will not affect appreciably the calibration of the instrument.

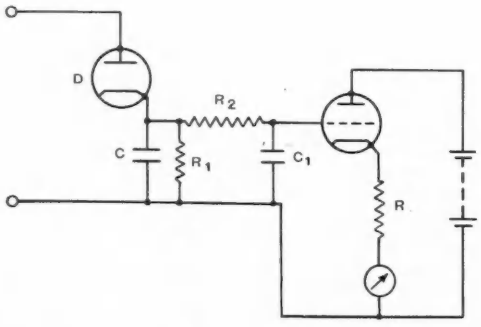

Fig. 18.—Schematic circuit diagram of degenerative D.C. amplifier for measuring the condenser voltage.

Fig. 19.—Diode peak voltmeter.

Fig. 19 shows a diode peak voltmeter in which the voltage is measured with an electrostatic voltmeter.

The diode is housed in a brass headpiece supported by a flexible metal tube. This arrangement enables the valve to be brought very close to the point at which the voltage is being measured. The diode used has small input capacitance (0·4 $\mu\mu$F), small distance between anode and cathode and short leads, so that the accuracy of measurement is about 3 per cent at 100 Mc./second, while the instrument can be used for approximate measurements up to 1000 Mc./second.

The smallest voltage that can be measured is determined by the range of the electrostatic instrument and its scale law. Greater sensitivity may be

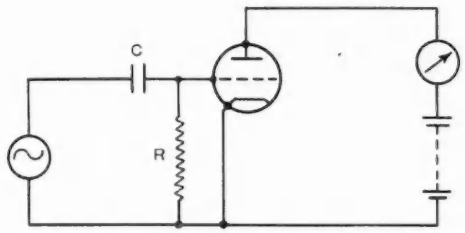

Fig. 20.—Simple grid-leak voltmeter.

obtained by applying an additional D.C. voltage in series with the electrostatic voltmeter so that it records over a more open part of the scale.

In the case where a triode is used for measuring the D.C. voltage, full scale deflection on a 200 micro-amp. instrument can be obtained for 1 volt input by a suitable choice of the cathode resistance.

(c) *Grid-Leak Voltmeter.*

The circuit of the simplest form of grid-leak voltmeter is shown in fig. 20. With no alternating voltage applied to the grid, current will flow through the resistance R, thus biasing the valve negatively; the bias depending on the value of the resistance. When an alternating voltage is superimposed, rectification takes place in the grid circuit; the current through the resistance increases and therefore the mean bias increases[12]. The operation is the same as that of the diode voltmeter: the grid behaves as the anode of the diode, and the change in anode current is taken as a measure of the change in the grid bias.

For values of grid current less than 1 micro-amp., the grid-current/grid-voltage characteristic of a triode such as the H63 is exponential. Hence the change in the grid bias can be calculated in exactly the same way as the change in anode potential for the diode, *i.e.*, the change ΔV in the D.C. potential of the grid is given by

$$\varepsilon^{K\Delta V}\,[K\Delta V + b] = b\,\mathrm{I}_o\,(KE)$$

If the anode-current/grid-voltage characteristic is linear, then this change in mean grid voltage ΔV will give rise to a change in anode current, $\Delta I_a = g_m\,\Delta V$, where g_m is the mutual conductance. Normally the anode current is only linear over a limited range of grid voltage, so that if the input voltage is large, "anode-bend" rectification will take place as well. The anode current is decreased by grid-leak rectification and increased by anode-bend rectification, so that if the latter takes place, the sensitivity is reduced.

Since both types of rectification are generally present, it is difficult to calculate the voltmeter response, and it is usual to calibrate the instrument experimentally.

(d) *"Anode-Bend" Voltmeters.*

The anode-bend voltmeter uses the curvature of the anode-current/grid-voltage characteristic of a valve for rectification, and the theory is so well known that only a brief reference to it is needed.

(i) *Square Law Type.*

The anode current of a triode valve can be expressed in the form

$$I_a = f\,(V_a + \mu V_g)$$

where V_a and V_g are the anode and grid voltages respectively. When there is no load in the anode circuit, V_a is constant so that

$$I_a = f\,(V_g) \quad - - - - - - - - - - \quad (2)$$

For triodes with a low μ value this function is a parabola for a considerable range of grid voltage,* so that (2) may be written

$$I_a = a + bV_g + cV_g^2$$

If a voltage $v = E\cos\omega t$ is impressed on the grid, then the change i in the anode current, as read on a D.C. meter, will be given by

$$i = \frac{E^2}{4}\,\frac{\delta^2 I_a}{\delta V_g^2} = \frac{E^2}{2}\cdot C$$

The rectified current is therefore proportional to the square of the input voltage, and the D.C. meter can be calibrated to read the R.M.S. value of the voltage: this calibration will hold whatever the wave-form of the input.

If higher even differential coefficients are present the calibration will not be square law, and if calibrated with a sinusoidal voltage it will not read correct R.M.S. values with a distorted input.

(ii) *Linear Type.*

It is sometimes convenient to have a more linear relationship between the change in anode current

* See Section "Valve Characteristics."

and the input voltage. This may be obtained by connecting a high resistance in the anode circuit of the valve. As the anode current increases, the mean anode potential falls, so that the rate of increase of mean anode current is lessened.[12]

The maximum alternating voltage which can be impressed on the grid, before the input resistance falls due to the rise of grid current, is limited by the value of the grid bias. If, however, the high resistance is included in the cathode lead, the voltage drop across this resistance not only lowers the anode potential but also acts as an additional negative bias.[13, 14] As the alternating voltage on the grid is increased, the anode current and negative grid bias increase and much larger voltages can therefore be applied to the grid before grid current flows. The voltmeter can also be designed to have several voltage ranges by changing the value of the resistance according to the range required. The resistance also improves the stability of the instrument with regard to changes in valve characteristics and electrode voltages.

A voltmeter designed in this way would read R.M.S. values with small input voltages, but would approximate to a peak voltmeter with large input voltages. A considerable error would therefore be introduced if the voltmeter were calibrated with R.M.S. voltages and used to measure large values of a distorted voltage.

The sensitivity of all rectifier type voltmeters can be increased considerably, if the "no-signal" anode current is balanced out, and a more sensitive current meter used. This can be done conveniently by means of a resistance bridge circuit. A limit of sensitivity

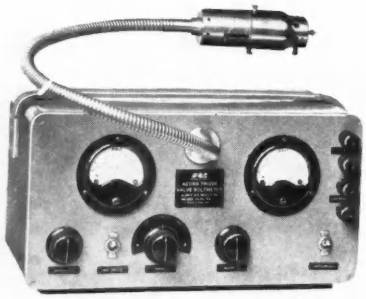

Fig. 21.—"Acorn" triode valve voltmeter.

is reached when variations in the H.T. and L.T. voltages to the valve give rise to variations in the zero reading, but these variations can be overcome to a large extent if another similar valve is placed in one arm of the bridge. If the voltages then change, the currents in the rectifying and balancing valve will change by similar amounts and the zero stability of the instrument will be greatly improved.

Fig. 21 shows a voltmeter of the linear type employing an "acorn" valve. As in the case of the diode voltmeter, the valve is mounted in a metal headpiece supported by a flexible metal tube. The "acorn" pentode is used in this instrument, because the arrangement of the valve leads enables more efficient by-passing condensers to be used than in the case of the triode. The input capacitance of the instrument is 3·5 $\mu\mu$F, and owing to the short electron transit time in the valve, the voltmeter is suitable for use at very high frequencies, the input impedance at 50 Mc./second being as high as 100,000 ohms.

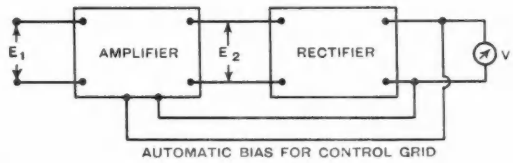

Fig. 22.—Schematic diagram of logarithmic voltmeter.

Another type of linear voltmeter, employing a negative "feed-back" amplifier is described by J. Greig and H. N. Wroe.[49] It is claimed that mean values of distorted low-frequency voltages of small amplitude can be accurately determined.

(iii) *Logarithmic Type.*

In cases where it is required to measure a large range of voltages, a voltmeter whose indications are proportional to the logarithm of the input voltage is a decided convenience. This is particularly the case in recording radio-field-strengths or in measuring the frequency response of amplifiers and loud speakers. Several arrangements for logarithmic indication have been devised, in which the curvature of the anode-current/grid-voltage characteristics of variable mu tetrode or pentode valves have been used for varying the amplification.

One arrangement[15] is illustrated schematically in fig. 22. The amplifier consists of one or more exponential valves, the number chosen depending on the range of input voltage E_1 to be measured. The amplification is controlled by an automatic grid bias, derived from the rectifier connected to the output terminals, and when the circuits are properly designed, the output voltage E_2 will be nearly constant over the range of input voltages to be measured. If the value of the automatic grid bias is indicated by a voltmeter, the deflection is approximately proportional to the logarithm of the input voltage.

It is possible* to design the grid of the valve such

* See Section, "Valve Characteristics."

that the anode-current/grid-voltage characteristic is given by $I_a = B\varepsilon^{bV_g}$ and therefore $g_m = Bb\varepsilon^{bV_g}$.

If V is the automatic grid bias, then the gain of the amplifier will be given by $\frac{E_2}{E_1} = C\varepsilon^{nbV}$ where C is a constant, and n the number of amplifier valves.

Hence $$V = \frac{1}{nb}\log_\varepsilon \frac{E_1 C}{E_2}$$

or $$V + \frac{1}{nb}\log_\varepsilon \frac{E_2}{C} = \frac{1}{nb}\log_\varepsilon E_1$$

Above a certain critical value, E_2 will be approximately constant, so that the automatic-grid bias V will be approximately proportional to log. E_1.

Other arrangements have been described by F. V. Hunt[16] and J. B. Rudd.[17]

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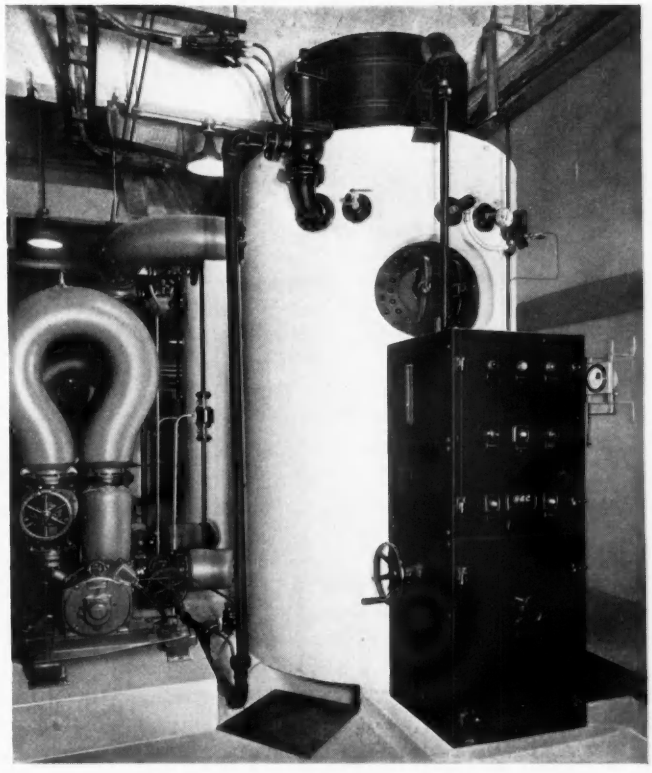
Thermal Storage Scheme at Poplar Town Hall



One of two high voltage electrode water heaters for the thermal storage central heating system at Poplar Town Hall, East London.

Each electrode heater is rated at 650 kW and operates from a three-phase supply at 6,600 volts. The automatic control cubicle is seen directly in front of the water heater.

Recent Progress in Electricity Meter Construction.

By S. JAMES, A.M.I.E.E.
Chief Engineer, Chamberlain & Hookham, Ltd.

THE Electricity Supply (Meters) Act, 1936, and the publication by the Electricity Commissioners of regulations concerning the examination, testing and regulating of electricity meters with a view to their certification, have influenced the design of these instruments and resulted in the introduction of special types, used particularly for testing purposes. The Electric Lighting Act, 1899, laid down the limits of error for electricity meters and made provision for the certification and sealing of meters by electrical inspectors. It also required that such meters should have been approved by the Board of Trade (succeeded later by the Electricity Commissioners).

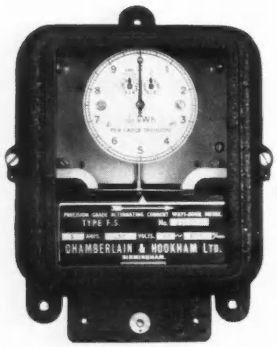


Fig. 1. Single-phase rotating substandard. Wall pattern. Type "FS."

Until recently, few supply authorities complied with the whole of these requirements and although in general no serious fault could be found with the accuracy of meters installed on consumers' premises, it was very unusual to find meters which had been certified by an independent authority. As a result of legal action by a consumer who disputed his account for electricity supplied, it was shown that the majority of meters installed could not be regarded as legal instruments notwithstanding the fact that they might be accurate within the legal limits. Following this decision the Electricity Supply (Meters) Act, 1936, was placed upon the Statute Book, and now all meters (with a few exceptions) must be approved by the Electricity Commissioners. In addition they must be certified as being correct within the legal limits by a meter examiner appointed by the Commissioners and must bear the Commissioners' seal before being installed on consumers' premises.

Apart from the foregoing, the testing equipment and the standard instruments used in the certification of meters must be in accordance with strict specifications drawn up by the Commissioners, and the methods of carrying out tests must conform to regulations designed to ensure the highest standard of accuracy.

In the following article, a description is given of a few of the special instruments developed by Chamberlain & Hookham, Limited, and intended for use as substandards in the testing of commercial grade meters. Some notes are also included relating to the latest designs of single-phase and polyphase meters together with important improvements in prepayment and heavy current meters.

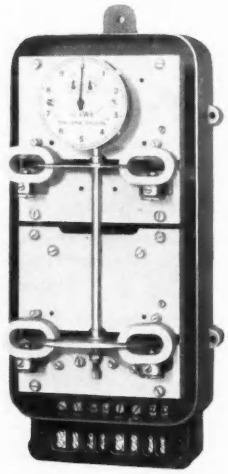


Fig. 2. Three-phase three-wire rotating substandard. Wall pattern. Type "FST."

PRECISION GRADE METERS.

A complete line of precision grade alternating current watt-hour meters has been developed to comply with the specification of the Electricity Commissioners for substandard rotating meters.

These instruments are intended for use in the certification of meters under the Electricity Supply (Meters) Act, 1936, and comprise the following patterns :

1. Single-phase wall pattern meter in cast iron case. Single range.
2. Three-phase three-wire two-element wall pattern meter in cast iron case. Single range.
3. Three-phase four-wire three-element wall pattern meter in cast iron case. Single range.
4. Single-phase portable pattern meter in polished wood case. Single range.
5. Single-phase portable pattern meter in polished wood case. Multi-range.
6. Three-phase three-wire two-element portable pattern meter in polished wood case. Single range.
7. Three-phase four-wire three-element portable pattern meter in polished wood case. Single range.

Fig. 3.—Single-phase rotating substandard. Portable Multi-range pattern.

In all the patterns above mentioned the measuring elements are alike. Two-element and three-element meters are built up with two or three single-phase elements respectively. Wall pattern meters are fitted with a registering mechanism reading in kilowatt-hours or alternatively, in revolutions of the meter rotors. Portable pattern meters have two registers, one of which reads in kilowatt-hours and the other in revolutions of the rotor. The latter registers a total of 50 revolutions and the edge of the rotor itself is divided into 100 parts so that it is possible to make very accurate observations. A resetting device is provided whereby the register reading revolutions of the rotor may be reset to zero after each observation. A tapping key in the pressure circuit of the meter enables the rotor to be brought to zero before starting a test.

A single-phase wall pattern meter is shown in fig. 1. The register reading in kilowatt-hours has a large pointer moving round a scale 10 inches in circumference and two smaller pointers reading up

Fig. 4.—Three-phase three-wire rotating substandard. Portable pattern.

to a total of 10 kWh on a 5 ampere 230 volt meter. Each small division on the large scale is one tenth of an inch in length and represents one watt-hour. Where it is desired to make long time tests of several days' or weeks' duration, a register of conventional pattern having six pointers and without the large index can be provided.

A three-phase three-wire wall pattern meter with the cover removed is shown in fig. 2. This has two single-phase elements coupled together, the general construction being similar to the single-phase meter. The three-phase four-wire meter is similar to the three-wire meter but has three elements and is correspondingly longer in dimensions.

A single-phase multi-range portable pattern meter is shown in fig. 3. A bakelite panel on the top of the instrument accommodates the terminals, the registering mechanism, the zero setting knob and the tapping key. Five current ranges and one voltage range can be provided in this instrument. One or two additional voltage ranges can be added by the use of external reactances if desired. The highest current range is rated at 100 amperes and the ranges on the meter illustrated are 1, 5, 10, 25 and 50 amperes.

A novel method of obtaining the various current ranges has been employed. A small current transformer having a nickel-iron core is combined with the meter and enclosed in the same case. This

transformer has a number of primary windings suitably disposed on the core and a single secondary connected directly to the meter current coil. The current coil is wound for 5 amperes but the meter is not intended for use independently of the transformer, consequently the 5 ampere range of the instrument is wound on the transformer. The advantage of this arrangement is a considerable increase in overall accuracy in multi-range rotating instruments which hitherto have been constructed with a number of windings on the current electromagnet, the different ranges being obtained by means of a multi-point switch. The use of a self-contained multi-range transformer with a simple current electromagnet in the meter element, permits the primary windings to be so disposed that very close agreement is achieved between the errors on the

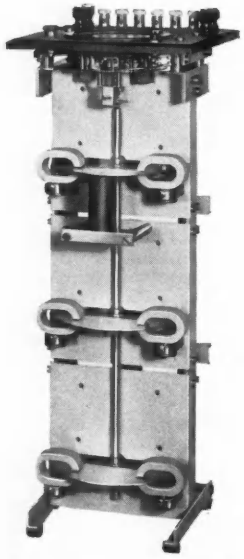


Fig. 5.—Three-phase four-wire rotating substandard. Portable pattern removed from case.

different ranges. By no alternative arrangement is such close agreement possible, and typical test results are given later in this article. Only portable single-phase rotating standard meters are supplied with this multi-range feature.

A three-phase three-wire two-element portable pattern meter in a polished wood case is shown in fig. 4. Its construction is generally similar to the single-phase instrument except that the depth of the case is increased to accommodate the two single-phase elements. Four current and four pressure terminals are arranged in a row at the back of the top panel, the pressure terminals being provided with insulated heads.

The measuring elements of a three-phase four-wire three-element portable pattern meter are shown in fig. 5. The long rotor shaft carrying the three rotor discs is tubular in section giving great rigidity and strength. It is supported on a spring seated jewel and the pivot and jewel can be removed as a single unit for inspection. If necessary it can be replaced easily by a new unit without any further adjustment. The upper disc in both polyphase models is subdivided into 100 divisions around its circumference as in the single-phase meter and a fiducial line on a pillar visible through the window and immediately below the edge of the disc permits accurate observation to less than one hundredth of a revolution. Two cobalt steel brake magnets embrace each disc and each magnet is independently adjustable.

In all the portable models, the measuring elements are arranged to stand upright when removed from the case and are supported on four rubber feet. This is a great convenience, as every part, both back and front, can be easily inspected and adjustments made if desired. The driving electromagnets are fitted on the rear of channel shaped steel frames and all adjustments are readily accessible. Jewelled footstep bearings are fitted to all the fast moving arbors in the registering mechanism with a view to reducing friction to a minimum.

All the single range meters previously described can be made in standard current ratings up to and including 50 amperes. A 1 ampere or 5 ampere meter can be used in conjunction with a precision current transformer for larger currents or where multi-ranges are desired. A suitable transformer will be described later.

In designing these instruments, great care has been taken to reduce the errors under all working conditions to a minimum. The observed errors are in all cases well within the limits specified in the British Standard Specification No. 37/1937, for precision grade meters and the limits permitted by the Electricity Commissioners for substandard alternating current watt-hour meters. The following brief summary of performance will indicate the high standard achieved. The tests apply to 50 cycle meters.

Errors Due to Variation in Load.

The errors at normal voltage and frequency with loads varying between 125 per cent and 10 per cent do not exceed plus or minus 0·3 per cent.

Errors Due to Variation in Voltage.

The errors at normal frequency and rated full load due to 10 per cent increase or decrease in voltage are zero.

Errors Due to Variation in Frequency.

The errors at normal voltage, rated current and unity power factor due to variation in frequency are as follows :

At 47·5 cycles meter registers 0·2 per cent fast.
At 52·5 cycles meter registers 0·2 per cent slow.
Under similar conditions but with a power factor of 0·5 lagging, the errors are :
At 47·5 cycles meter registers 0·1 per cent fast.
At 52·5 cycles meter registers 0·3 per cent slow.

Errors Due to Heating by Main Current.

The change in the error from switching on full load when cold until the error becomes constant is 0·2 per cent at unity power factor, the meter registering fast. There is zero change at 0·5 power factor.

Errors in Multi-range Meters.

The change in the error of a multi-range meter due to changing from one current range to another does not vary by more than 0·1 per cent approximately from the mean error at any particular load between 125 per cent rated current and 10 per cent rated current. The table below indicates the magnitude of the change, in a multi-range meter having six current ranges.

Consideration of the foregoing performance data will indicate the suitability of these instruments for precise and accurate testing by the method of comparing the registration of the meter to be tested against the registration of the standard meter. The convenience of this method is generally recognized in the case of single-phase meters, although many testing engineers still continue to use indicating wattmeters and a stop watch with a controlled load when testing polyphase meters. The probable reason for this is that, hitherto, polyphase rotating standards of the requisite accuracy have not been available, particularly with regard to three-phase four-wire three-element meters. The testing of three-element meters has presented many difficulties owing to the fact that (so far as the author is aware) there is no commercial three-element dynamometer wattmeter available at a reasonable price for measuring the load. As a consequence it has been necessary to use three single-phase instruments or one three-phase three-wire and one single-phase instrument and this has necessitated two or more observers to control and regulate the load. These difficulties disappear when a three-element rotating standard is used and more accurate testing with less complication in method is now possible by the use of these new instruments.

Rated current in %	Power factor	PERCENTAGE ERROR IN REGISTRATION Current range in amperes 1	2.5	5	10	25	50	Mean error
125	1.0	0.3 –	0.3 –	0.2 –	0.3 –	0.2 –	0.3 –	0.2 –
100	1.0	0.1 –	0.0	0.0	0.1 –	0.0	0.1 –	0.0
75	1.0	0.0	0.1 +	0.2 +	0.1 +	0.2 +	0.1 +	0.1 +
50	1.0	0.1 +	0.1 +	0.2 +	0.1 +	0.2 +	0.1 +	0.1 +
25	1.0	0.1 –	0.1 –	0.0	0.1 –	0.0	0.0	0.0
10	1.0	0.1 –	0.3 –	0.2 –	0.2 –	0.2 –	0.3 –	0.2 –
5	1.0	0.1 –	0.2 –	0.4 –	0.5 –	0.3 –	0.4 –	0.3 –
125	0.5	0.4 –	0.4 –	0.3 –	0.5 –	0.3 –	0.3 –	0.4 –
50	0.5	0.0	0.0	0.1 +	0.1 –	0.1 +	0.0	0.0
10	0.5	0.0	0.2 –	0.2 –	0.3 –	0.2 –	0.3 –	0.2 –

TECHNICAL DATA.

	Single-phase 230 volts	Three-phase three-wire 3×400V.	Three-phase four-wire 3×230V.
Full load torque ..	7.5 cm-grs.	12.6 cm-grs.	18.9 cm-grs.
Full load speed ..	10 r.p.m. (1 kW)	10 r.p.m. (4 kW)	10 r.p.m. (3 kW)
Shunt loss	0.9 watt.	2×0.7 watt.	3×0.9 watt.
Series loss	0.7 VA.	2×0.7 VA	3×0.7 VA
Weight of rotor ..	40 grammes.	78 grammes.	113 grammes.

The figures for full load speed and series loss in this table refer to a 5 ampere meter.

Errors Due to Heating by the Voltage Circuit.

The change in the error at 125 per cent and 25 per cent rated current and at unity power factor, due to heating in the voltage circuit, is zero.

Errors Due to Stray Fields.

The change in the error of a portable pattern meter in wood case, without any screening, when tested in the manner prescribed in B.S.S. 37/1937 with rated current, the stray fields being in phase and also 60° out of phase, is 0·1 per cent, the meter registering fast in each case.

Errors Due to Variation in Air Temperature.

The change in the error due to an increase of 1°C in air temperature measured over the range 17°C to 32°C is shown below :

Power factor	Change of error At 100% current	At 10% current
1.0	0.04% fast	0.05 fast
0.5 lag.	0.01% ,,	0.05 ,,

PRECISION GRADE CURRENT TRANSFORMERS.

For use in connection with precision grade meters having a single current range, precision grade multi-range current transformers are necessary. These transformers must have an accuracy at least

Fig. 6.—Multi-range portable precision current transformer.

equal to Class "A.L." in British Standard Specification No. 81/1936, and a variety of types have been developed by Chamberlain & Hookham, Ltd., for this purpose. One of these was described previously

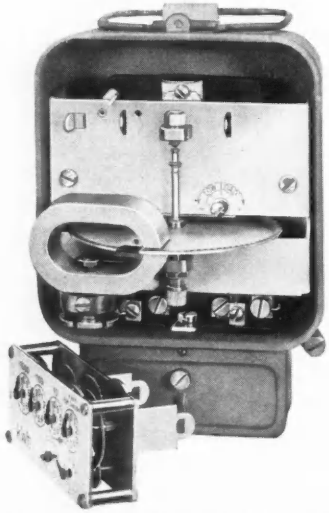


Fig. 7.—Single-phase meter, type "J" with counting train removed.

in this Journal,[1] having a maximum ratio error of 0·02 per cent and a maximum error in phase angle of 2·0 minutes. The transformer has six current ranges, the maximum rating being 100 amperes.

1 G.E.C. Journal, Vol. X., No. 1, February 1939, p. 42.

Another type of transformer of this class is illustrated in fig. 6, which shows a transformer for a maximum rating of 3,000 amperes. The secondary which is wound for either 5 amperes or 1 ampere has three tappings brought out to four terminals. A primary in four sections is brought out to links and may be connected in series, series-parallel or parallel, giving three ranges for each secondary tapping. The highest range available by means of the link connections is 100 amperes but higher ranges may be obtained by winding turns of flexible cable through the tubular openings projecting through the case of the transformer. In this manner a large number of ratios is available. Other types of precision grade transformer are also available covering every possible requirement.

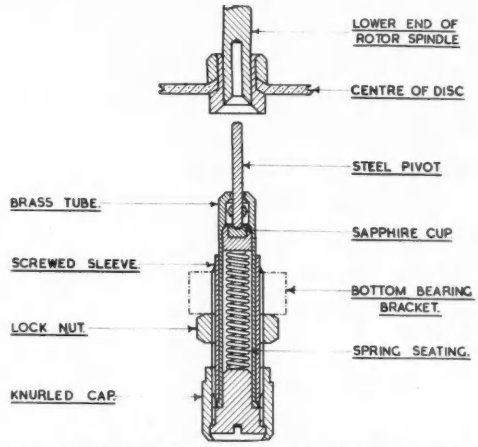


Fig. 8.—Bottom bearing unit for alternating current meters.

COMMERCIAL GRADE METERS.

A line of commercial grade alternating current watt-hour meters has recently been completed comprising single-phase, three-phase three-wire two-element and three-phase four-wire three-element patterns. All these are available as two-rate meters if desired. In addition, a new pattern of prepayment meter having a divided case, giving access to the prepayment mechanism without unsealing the measuring element, has been produced. Another development which permits the maximum current rating of self contained meters to be extended, has also been introduced. This is applicable to single and polyphase meters.

The single-phase meter has already been briefly described in a previous issue of this Journal,[2] but the following additional notes may be of interest. The meter without its cover and with the counting train removed is shown in fig. 7. A novel method of fixing the counter has been adopted. Two brackets projecting from the back of the counter are arranged to pass through two vertical slits in the meter frame. A

2 G.E.C. Journal, Vol. VIII., No. 1, February 1936, p. 40.

sliding bolt is provided behind the frame, and when the counter is placed in position with the ends of the brackets passing through the slits, the bolt may be moved to the right, securely locking the counter and giving a very rigid fixing.

The rotor may be removed in a few seconds without disturbing the brake magnet, by slackening the top bearing screw a few turns and removing the bottom bearing unit (fig. 8). This consists of a hardened and tempered steel pivot, the lower end of which is ground to a true hemisphere and highly polished. It rests on a sapphire cup which is also highly polished and is supported on a spring seating contained within a brass tube closed at the lower end by means of a knurled cap. The bottom bearing bracket is tapped to receive a sleeve screwed externally and held in position by a lock nut. This sleeve houses the brass tube containing the pivot and jewel, and the knurled cap on the tube screws onto the sleeve. A hole in the lower end of the rotor spindle receives the pivot which can slip easily into position. The correct setting of the pivot and jewel is determined by raising or lowering the screwed sleeve which is finally locked in position in the bottom bearing bracket by means of the lock nut. Once the correct position has been determined the bottom bearing unit may be removed and replaced or a new unit may be substituted without need for any further adjustment, as all units are interchangeable.

The error curve of the meter is substantially flat on loads up to 200 per cent of rated current or even more. In order to achieve this result a very powerful magnetic brake is necessary. It is common practice to use two brake magnets of either chrome or tungsten steel where a powerful brake is required but in the Chamberlain & Hookham Type "J" meter a single magnet of cobalt steel is employed which, although a much more expensive alloy than either chrome or tungsten steel, has several advantages which offset the extra cost. By its use the weight of the meter is reduced and also the overall dimensions of the case. The magnet is more permanent and less influenced by external demagnetizing influences. The coercive force of the steel may be regarded as a measure of its magnetic permanence. The coercive force of chrome and tungsten steels is between 55 and 65 units whereas the coercive force of the cobalt steel in the Type "J" magnets is 160 to 180 units. Further, a demagnetizing force which will completely demagnetize a chrome or tungsten steel magnet will have practically no effect on a cobalt steel magnet.

The meter frame consists of two parts, the back portion comprising a flat plate carrying the driving electromagnets and the front portion consisting of a channel shaped member carrying the rotor, counter and brake magnet. These are shown in fig. 9, in which the two parts are separated. The back plate is held in the meter case by two screws having elongated heads which serve as spacing pillars maintaining the correct distance between the front and back plates. The front plate rests on these pillars and is accurately located with respect to the back plate by means of interengaging steps on both halves.

In the three-phase three-wire two-element meter, Type "J.T." and the three-phase four-wire three-element meter, Type "J.T.4," similar elements are employed and the meter frame is constructed on

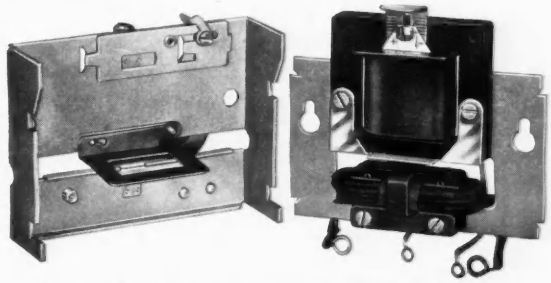


Fig. 9.—Components of single-phase meter frame.

similar principles to those adopted in the single-phase meter. Fig. 10 shows the outside appearance of a three-phase three-wire meter fitted in this instance with a two-rate counting train, and fig. 11 shows the interior of a three-phase four-wire three-element meter having a terminal block at each side

Fig. 10.—Three-phase three-wire meter with two-rate counting train.

and arranged to measure the consumption in two parallel circuits.

The frames in the two polyphase meters differ from the single-phase frame in that both back and front plates are of channel section. The back plate is slightly wider than the front and carries all the electromagnets. The front plate is provided with projecting tongues on the edges which engage with slits in the back plate in order to ensure accurate location of the one with the other. Fig. 12 shows the interior of a three-phase four-wire meter in which the two halves of the frame are separated.

A noteworthy achievement is in connection with alternating current meters for relatively large currents of the order of 100 to 200 amperes. Hitherto the largest whole current meters made, either in single-phase or polyphase types have been rated at 100 amperes, and because of the difficulty of winding the series electromagnets with the thick and bulky conductor and also of making reliable connections between this conductor and the terminal block, it is a common practice to confine whole current meters to ratings of 50 amperes as a maximum. Where 100 ampere whole current meters have been supplied, it has been recognised that great care is necessary in making the connections to the supply and the consumer's circuit in order to avoid overheating of the terminals and the overload capacity of the meter has been strictly limited. In polyphase meters a further disadvantage lies in the fact that the interaction between one element and another has been increased owing to the increased stray fields inside the meter case arising from the heavy current carrying conductors. This interaction has resulted in the inherent errors of 100 ampere whole current meters being greater than the lower current ratings.

It has thus been the practice to limit whole current meters to a maximum rating of 50 amperes and for currents exceeding this value, current transformers have been used. The space occupied by the current transformers invariably exceeds the space

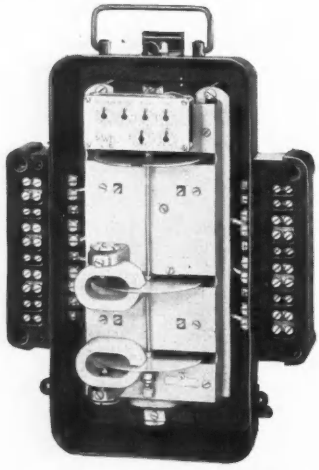


Fig. 11.—Three-phase four-wire three-element meter for two parallel circuits.

occupied by the meter and in the case of polyphase meters, where two or three transformers are necessary, this additional space is considerable.

To overcome these disadvantages, Chamberlain & Hookham, Ltd., have constructed meters integral with the current transformers in ratings of 100, 150 and 200 amperes. A three-phase three-wire meter of 100 ampere rating is shown in fig. 13, the cover of the terminal compartment being removed to show the current transformers. The transformers have nickel iron cores on which the secondaries are wound. The primaries consist of short copper rods passed through the cores and soldered into the terminal blocks at each end. The meter current coils are

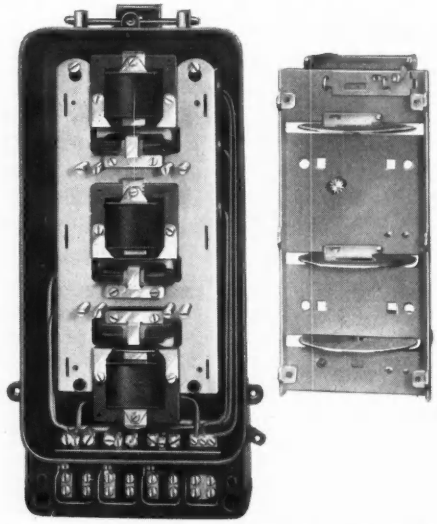


Fig. 12.—Three-phase four-wire meter showing frame construction.

wound for 5 amperes and the connections are made to a small terminal block immediately above the transformers. The burden on the transformers is very small owing to the short length of lead between the secondaries and the current coils and to the very low volt-ampere consumption of the latter. It is not intended that any additional burden shall be connected to the transformers and the use of nickel iron in the cores permits bar primaries to be employed with consequent small overall dimensions.

A three-phase four-wire three-element meter has three transformers and in fig. 14 a set of 200 ampere transformers for a four-wire meter is shown. The lower transformer has the cable sockets removed and it will be observed that the transformer becomes smaller as the rated primary current becomes greater. The advantages of this construction are considerable: not only is the accuracy of the meter improved in the 100 ampere rating by eliminating interaction between elements but more reliable connections are assured. In the 150 and 200 ampere ratings there is a very considerable saving in the space normally occupied by separate transformers and the possibility of incorrect connections between transformers and meter is eliminated, since these are made by the manufacturer and are not left to be carried out by the meter fixer on the consumer's premises. Since the transformers are permanently connected to the meter there is no possibility of errors arising due to, say, the transformer which is connected to the current

coil in the red phase when tested in the test room, being connected to the current coil in the blue phase on consumer's premises. A very great saving in installation costs follows from the use of this combination since the cost of fixing separate transformers and wiring from these to the meter is entirely eliminated.

PREPAYMENT METER IN DIVIDED CASE.

Since July 1st, 1938, all meters to be installed on consumers' premises must previously be certified

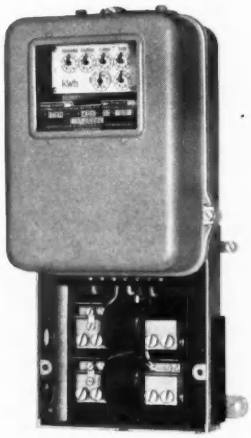


Fig. 13.—Three-phase three-wire meter with self-contained transformers.

by a meter examiner on behalf of the Electricity Commissioners and must bear the official seal. If the seal is broken the meter ceases to be a legal instrument and must again be certified and resealed. Prepayment meters are sometimes subjected to a certain amount of abuse by consumers in attempting fraudulent manipulation or the insertion of metal discs and coins of incorrect denomination. Sometimes as a result, the meter is rendered inoperative and it becomes necessary for a mechanic to visit the consumer's premises in order to make the meter serviceable. This usually entails the removal of the meter cover in order to obtain access to the mechanism and for this purpose the seals must be broken. Following the repair, resealing is necessary and a formal declaration must be made in an official document setting out the reason for breaking the seals and stating that no interference has been made with the adjustments of the meter. The alternative to this procedure is to remove the offending meter and replace it by another, the repair being carried out in the test room. This method, however, is usually avoided on account of the expense.

In order to obviate these difficulties the prepayment meter shown in fig. 15, has been developed. The meter element and the prepayment mechanism are already well known to supply authorities but the case in which they are enclosed embodies several novel features. The case, which is moulded in synthetic resin, is divided into two compartments, one of which encloses the meter element, and the other contains the prepayment mechanism and the rental attachment. When the main cover is in position and sealed, the meter element is completely inaccessible. The upper part of the main cover has a hinged portion which can be lifted to expose the prepayment mechanism. Fig. 15 shows the hinged portion in the open position and the whole of the mechanism is completely accessible. If desired the mechanism can be removed or exchanged on the consumer's premises without interfering in any way with the meter element. The mechanical connection between the counting train of the meter and the coin freed portion is by means of a wheel in the counting train which projects through a narrow slit in the partition dividing the case. Only the edge of the wheel is visible and this meshes with a corresponding wheel in the coin freed portion.

When the hinged portion of the cover is closed it is secured by means of a sliding bolt which may be retained either by means of a separate seal or by the padlock on the coin compartment, at the option of the supply authority. If a separate seal is desired the sliding bolt is inserted from left to right and a wire seal at the end prevents its withdrawal. The alternative method is to insert the sliding bolt from right to left. This can only be accomplished when the coin compartment is withdrawn, and when replaced it is impossible to remove the bolt. By the first method the mechanism is not accessible to the

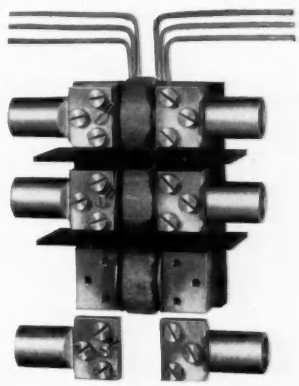


Fig. 14.—Transformer units for 200 amp. three-phase four-wire meter.

collector nor is the cash accessible to the official who may for example be called upon to change the price per kWh. The second method obviates the use of a separate seal.

The meter may be obtained with or without the rental attachment shown in the upper left hand

corner, and if in the first instance this attachment is not required, it can be added at a later date in a few seconds. All that is necessary to embody the rental attachment is to remove two screws, slip the rental attachment into position and replace the screws. Dowel pins ensure correct alignment of the gears and no skill is required in this operation. The electrical connection is made by two pins and sockets.

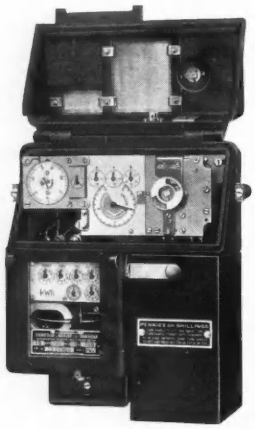
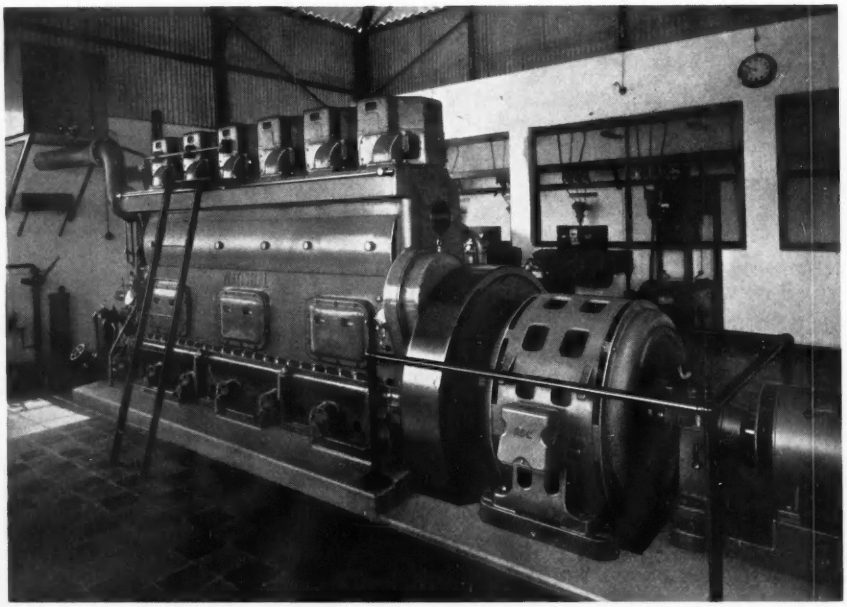


Fig. 15.—Prepayment meter in divided case. Hinged cover open.

The prepayment mechanism operates with pennies or shillings or both. The price per kWh can be altered in an instant by the simple exchange of a gear unit which clips in position. The exchange of the gear unit likewise requires no skill as correct meshing of the wheels is automatically ensured, and the operation is accomplished with one hand.

If an incorrect or bent coin is inserted which the mechanism will not accept, it can be released by a button on the top of the cover and the rejected coin is returned to the consumer through a slot at the side of the coin compartment. The latter has capacity for 500 pennies and is constructed of steel. The whole mechanism is of the simplest character and in combination with the exclusive features previously described ensures minimum cost of maintenance. The complete meter has been approved by the Electricity Commissioners.

Generating Plant at the Buenos Aires Waterworks Co., Ltd.



A 200 kW alternator, 3000/3,300 volts, installed at the Villa Calzada pumping station of the Buenos Aires Waterworks Co., Ltd., to the order of the British American Construction Co., Ltd. The alternator is oil engine driven and provides power for the motors driving the bore pumps. A duplicate set is being supplied.

The G.E.C. Twelve-channel Carrier System for Telephone Cable Circuits.

By C. RILEY, B.Sc.
G.E.C. Telephone Works.

In the G.E.C. Journal for August, 1938, a description was given of one of the most important developments of recent years in long distance telephony—the introduction of the multi-channel carrier telephone cable. In this article details of equipment employed and mode of operation are given, together with actual installations on the British Post Office trunk system.

THE volume of telephone traffic handled by the trunk network of this country has increased very rapidly during recent years. At the same time the Post Office has been aiming at giving on trunk calls a "no delay" service which would enable a calling subscriber to be connected immediately to another subscriber in a distant town. These two factors together have made necessary the provision of considerable numbers of additional trunk circuits, especially between the large centres of population, such as London, Birmingham, Manchester, Bristol, Leeds and Glasgow, which act as distribution points for their particular areas and are known as "zone centres." Recent advances in carrier telephony, enabling a number of channels of communication to be provided over one pair of wires, offered an obvious solution to the problem of providing large blocks of circuits between the zone centres, both at reasonable cost and in a comparatively short time. For technical reasons and for reasons of convenience, twelve channels per pair of wires was decided upon, and the Post Office are providing most of their zone-to-zone communication by 12-channel carrier systems. In many cases, similar systems are being used for extension to the

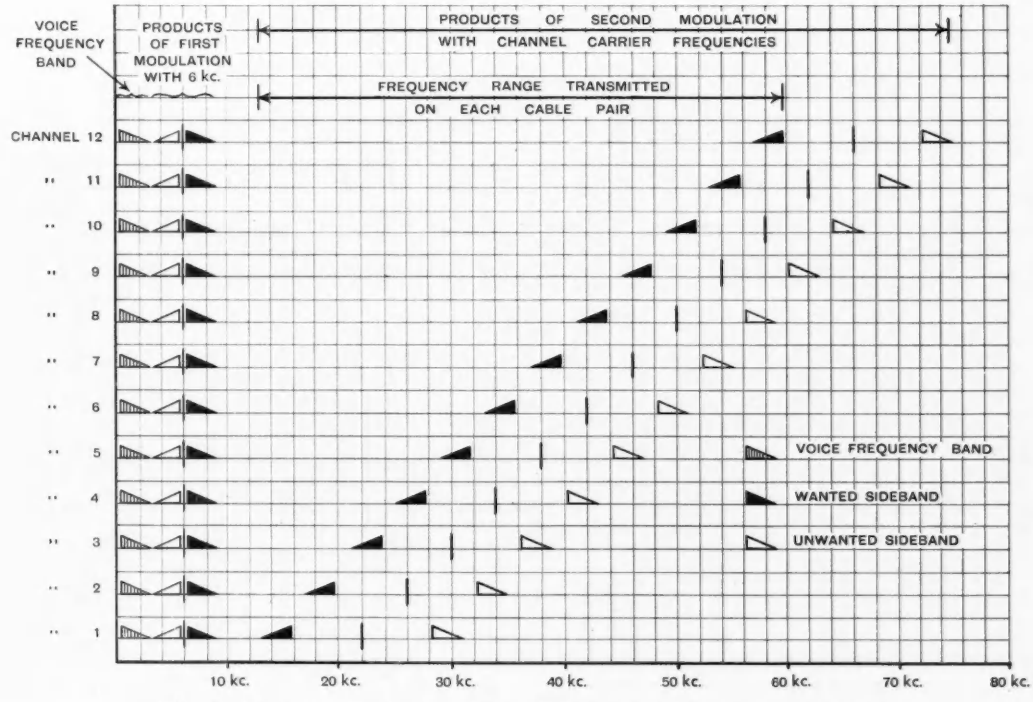


Fig. 1.—Diagram showing position of sidebands in frequency spectrum.

smaller distribution points, known as "group centres" within the zones.

In carrier telephony, a steady frequency, above the audible range, is generated and then modulated with the frequencies produced by speech. This process of modulation produces "sideband" frequencies which extend on each side of the steady or "carrier" frequency over bands equal to the speech band used for modulation. For the reproduction of the speech at the receiving end, only one sideband need be transmitted. The other sideband and the carrier frequency are therefore suppressed at the sending end, resulting in economy of equipment and a general simplification of the whole system. At the receiving end, a process of demodulation enables the original speech to be reproduced from the transmitted sideband, by using a carrier of the same frequency as at the sending end, but, of course, generated locally.

The modulation of a carrier frequency by a speech-frequency band results in the latter appearing as a sideband and therefore being shifted to a higher position in the frequency spectrum. By using, say, twelve different carrier frequencies spaced at suitable intervals, the result of modulating these with speech frequency bands will be to produce sidebands on the same spacing as the original carrier frequencies. Provided that these sidebands can be transmitted and at the receiving end can be selected and undergo the process of demodulation without mutual interference, it is evident that twelve different channels of communication can be obtained on the same pair of wires. Electrical networks known as "filters" are used for separating the different frequency bands from one another and for selecting the one required at each point. A "high-pass" filter offers very small attenuation to frequencies above its designed "cut-off" point but great attenuation to frequencies below it. A "low-pass" filter, on the other hand, offers a small attenuation to frequencies below, and a great attenuation to frequencies above, the cut-off point. A "band-pass" filter offers low attenuation to frequencies between two points and a high attenuation to frequencies outside this range, either above or below.

The limit to the number of channels which can be established over a given pair of wires is imposed by the difficulties that are encountered at the high frequencies which become necessary as the number of channels is increased. Attenuation, and interference between circuits in a cable—known as "cross-talk"—both increase with frequency, but on the specially-designed cables which have already been described in this Journal,[1] it is possible to transmit a range of frequencies sufficiently wide for at least twelve channels.

By using two different frequencies, one for each direction within a channel, transmission in each direction can be obtained on each pair of wires, but the most satisfactory results and the greatest simplification of equipment are obtained by using separate cables for the two directions of transmission, the same frequencies then being used both ways. This is the method most frequently adopted and is employed in the G.E.C. system, a description of which follows.

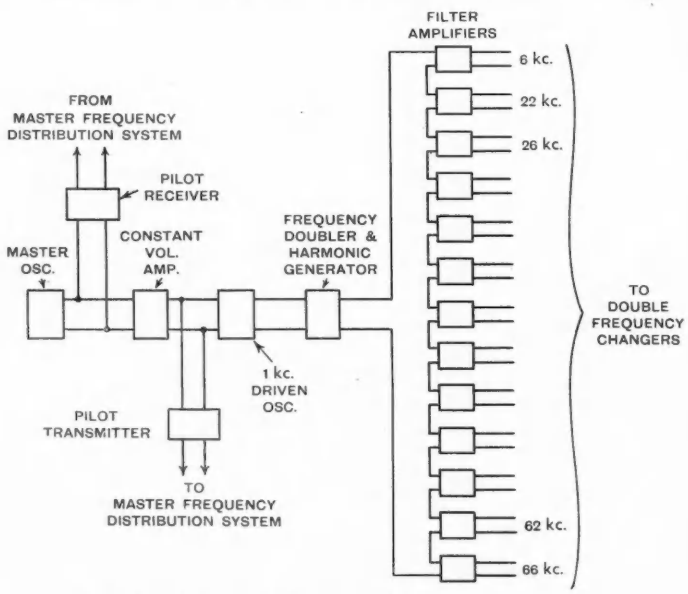


Fig. 2.—Schematic diagram of frequency-generation equipment.

CARRIER FREQUENCY GENERATION.

It will be evident that a 12-channel system requires twelve carrier frequencies, sufficiently spaced in the frequency spectrum to avoid mutual interference. The spacing allotted depends upon the speech band to be transmitted and upon the margin required by the filters. Good commercial speech is covered by the range 300 to 2,800 cyc., *i.e.*, by a band width of 2.5 kc, and with the necessary margins allowed on each side, the internationally-adopted carrier spacing is 4 kc.

For various reasons, the lowest frequency employed in the 12-channel system is in the region of 12 kc, which means that the highest is approximately 60 kc. Consider a carrier of, say, 58 kc; its two sidebands, if it were modulated by the speech band of 300 to 2,800 cyc., would extend upwards from 58.3 kc and downwards from 57.7 kc. That is to say that there would be a margin between them of only 0.6 kc, whereas at these higher frequencies a greater margin is preferable to assist the filters in separating the wanted sideband from its unwanted counterpart. Therefore, instead of allowing the twelve speech bands directly to modulate the carriers, a process of double modulation

1 G.E.C. Journal, Vol. IX., No. 3, August, 1938.

is employed. In this, as shown in fig. 1, each speech band first modulates a low frequency, for which 6 kc has been chosen. The upper sideband, extending from 6.3 kc to 8.8 kc, is selected in each instance, and it is this sideband instead of the actual speech frequencies that modulates the carrier. This second modulation produces sidebands which are 12.6 kc apart, a margin that is adequate for effective separation by simple filters.

The frequency-generation equipment has, therefore, to supply twelve carrier frequencies for the twelve channels and a frequency of 6 kc common to all channels. The carrier frequencies range from 22 kc to 66 kc.

Fig. 2 shows a schematic diagram of the frequency-generation equipment. The master oscillator generates a frequency of 1 kc, which is supplied through a constant-volume amplifier to a 1 kc driven oscillator. This latter oscillator is held in step with the master frequency, and its output is applied to a frequency doubler and harmonic generator, which produces a square wave of 2 kc frequency. This contains all the odd harmonics, which are in 4 kc steps, and can be tapped to provide the required carrier frequencies. Selection of the harmonics is made by filter-amplifiers, each of which is designed to pass its allotted frequency and to reject others. At the output sides of the filter-amplifiers, therefore, appear the twelve carrier frequencies and the 6 kc common to all channels.

Were there no possibility of failure, one master oscillator could serve all 12-channel terminals in the country, thus ensuring complete synchronization. A failure would, however, be serious, and therefore a number of master oscillators is to be provided at different points, their outputs serving the stations at which they are installed and other stations also by means of pilot transmitters connected to a distribution network. As is shown in fig. 2, a pilot transmitter is fed from the 1 kc driven oscillator, the output of which modulates in the transmitter a frequency of 10 kc. The carrier and lower sideband are transmitted over a cable pair to a distant station, equipped, as shown in fig. 2, with a pilot receiver. This receives the incoming 10 kc and sideband, and by means of an arrangement of dry-plate rectifiers and a simple filter, suppresses all frequencies but 1 kc. This can be passed to the 1 kc driven oscillator as an alternative source of supply to that of the master oscillator.

With the necessary frequencies thus available, the operation of the apparatus in a channel can be examined.

OPERATION.

In fig. 3, the two-wire line from the trunk switchboard is connected to a termination unit, from which there are two circuits, one for transmitting and one for receiving. This termination may or may not be at the 12-channel station, and provision is therefore made for the inclusion of voice-frequency amplifiers should the four-wire circuit be of sufficient length to necessitate them.

In the *transmit* path the speech currents pass to the double frequency-changer, associated with which is a speech-voltage limiter. The object of this is to limit the peak voltages to a maximum amplitude corresponding to −1 db with respect to 1 mW, in

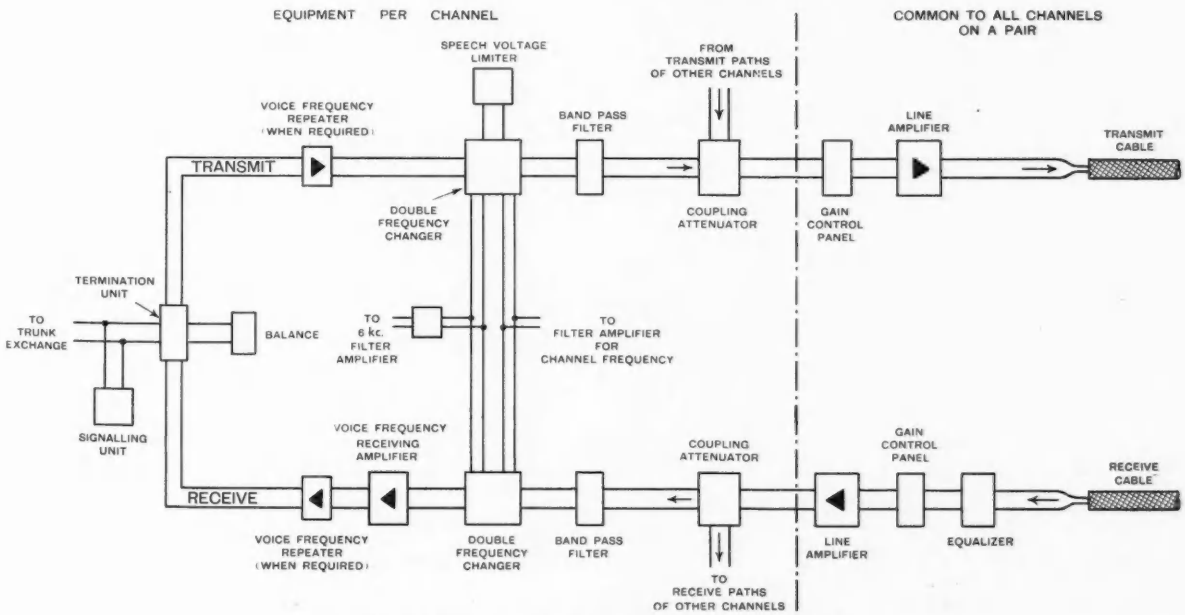


Fig. 3.—Schematic diagram of equipment in a channel.

order that there shall be no tendency towards interference between channels. In the double frequency-changer the speech frequencies are applied to a dry-plate rectifier bridge which is fed also with 6 kc from the generation equipment. The resulting modulation produces two sidebands, the carrier itself being suppressed as a result of the balanced arrangement of the bridge. The upper sideband is selected by a filter included in the double frequency-changer, and is passed to a second rectifier bridge, which is fed with the appropriate channel frequency. This second modulation produces two sidebands, of which one is passed by the band-pass filter that follows the which one is passed for the second demodulation process, this time with 6 kc. A speech-band limiting filter passes the sideband 300 to 2,800 cyc. and the output of the double frequency-changer is therefore the original speech frequencies. These pass through a receiving amplifier, and then to the two-wire/four-wire termination unit, being amplified again, if necessary. From the termination unit they pass to the trunk exchange.

The operation in the other eleven channels is exactly the same, each double frequency-changer being fed with 6 kc and its appropriate channel frequency. The schematic diagram for a group of

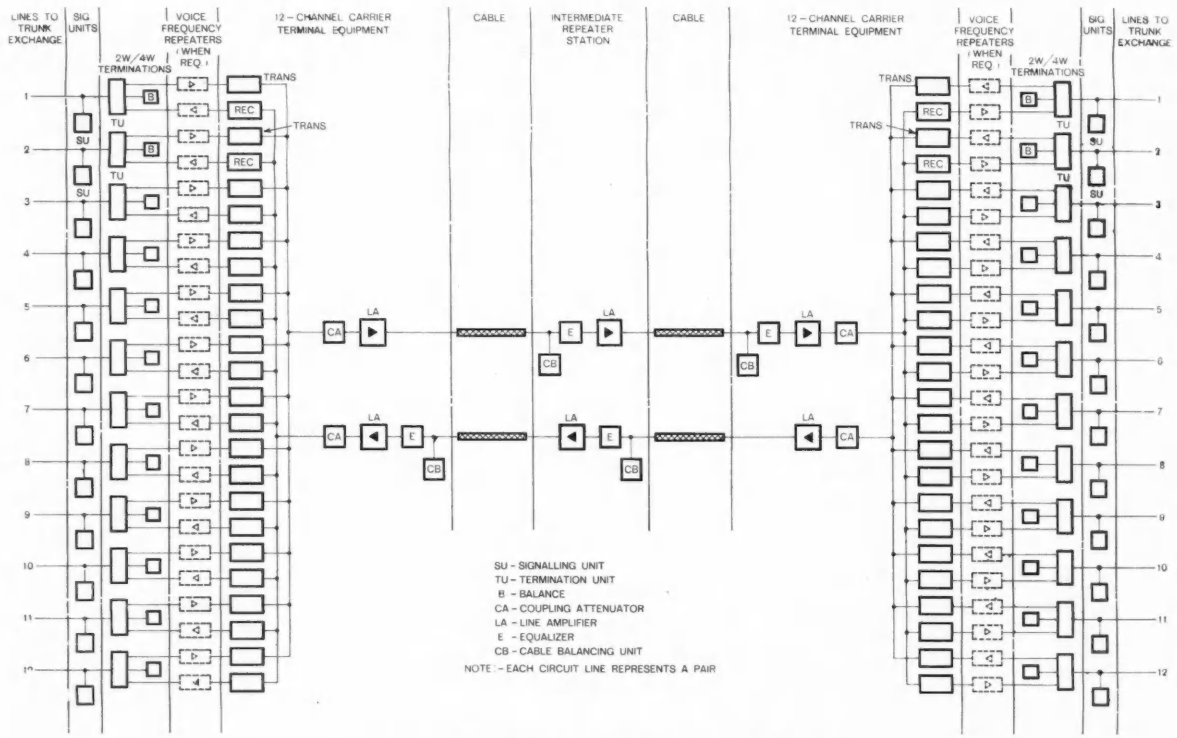


Fig. 4.—Arrangement of one 12-channel group.

double frequency-changer. Passing through a coupling attenuator, the sideband is amplified by a line amplifier, the gain of which can be regulated by a gain control panel. The amplified sideband then passes to the cable pair.

At the receiving end, the equipment is exactly as that shown in the *receive* path of fig. 3. The incoming sideband is equalised to give compensation for the greater line attenuation at the higher frequencies, and then passes to the line amplifier. In amplified form, it passes through the coupling attenuator and is selected by the appropriate band-pass filter. In the double frequency-changer it meets the carrier frequency for the channel, the resulting demodulation producing two sidebands, of twelve channels is given in fig. 4, which shows two terminals and an intermediate repeater station. The equipment at this latter station consists of line amplifiers, with equalizers to compensate for the unequal attenuation of the component frequencies of the 12-channel group in the course of their transmission over the line. It should be noted that the amplifier is common to all twelve channels on a pair, an important fact that assists considerably the economics of twelve-channel working, because twelve V.F. circuits, although requiring amplification at less frequent intervals in the course of transmission, would necessitate twelve separate amplifiers.

The intermediate amplifiers are installed when possible at main-line repeater stations. Generally,

however, this cannot be arranged, and they are then accommodated in specially-built stations, which are unattended.

Fig. 5.—Terminal equipment at Cambridge.

SIGNALLING.

A voice-frequency signalling scheme similar to that applied to V.F. trunk lines is employed on the 12-channel system. Ringing current at 17 cyc., incoming from the exchange, is converted by a signalling unit into a 500 cyc. current interrupted twenty times per second. This 500 cyc./20 cyc.current modulates the carrier exactly as if it were speech. The resultant side-band passes over the channel on which signalling is required and at the distant end is demodulated to produce a 500 cyc./20 cyc. current. A receiving signalling unit, exactly the same as that at the transmitting end but operating in the reverse direction, responds to the interrupted current to feed 17 cyc. current for signalling the trunk switchboard. Special arrangements are made to ensure that the signalling unit shall remain unaffected by predominant 500 cyc. components of speech.

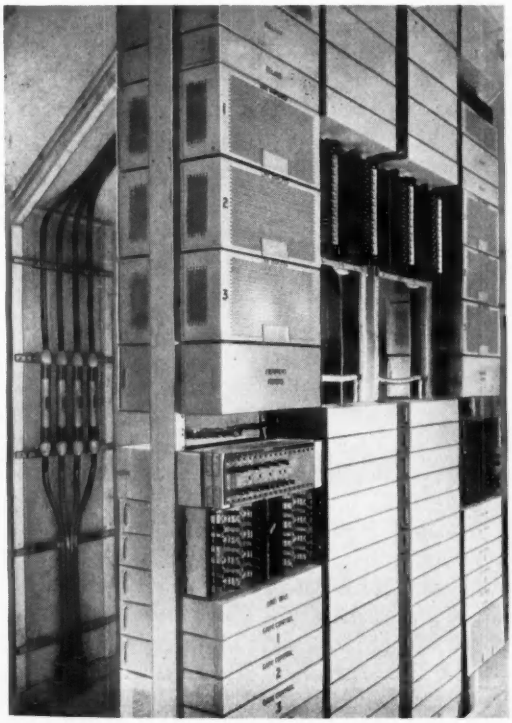


Fig. 6.—Line amplifiers and cable terminations at the intermediate repeater station at Little Stukeley (London-Carlisle circuits).

EQUIPMENT.

The apparatus in a 12-channel system more or less automatically falls into the following distinct classes (*a*) the separate channel apparatus for one group of twelve channels, termed collectively—group equipment ; (*b*) the apparatus for generating the frequencies required by all the groups—generator equipment ; (*c*) pilot and master-frequency equipment ; (*d*) line amplifiers ; and (*e*) equalizers.

The design of equipment bay standardized by the British Post Office for transmission equipment is used in the 12-channel system. A bay is 10ft. 6in. high and 1ft. 8½in. wide, and carries, on both its faces, mounting plates on which are fitted the components.

There is a considerable amount of equipment common to a number of circuits. For example, a line amplifier is common to twelve channels, whilst the generator equipment is common to twenty-four groups of twelve channels. Such apparatus failures as might be anticipated in service assume considerable significance if the effect is likely to be felt on a number of valuable communication channels. Routine attention is therefore an essential part of the operating procedure, the object being to trace incipient faults before they have an opportunity to develop. To enable equipment in service to be removed for testing, certain spares are provided and arranged for almost instantaneous switching into service. These are referred to in the following descriptions of the various equipment bays.

GROUP EQUIPMENT.

This consists of twelve *receive* V.F. amplifiers (one per channel), two 6 kc amplifiers (of which one is a spare), twelve *transmit* and twelve *receive* double frequency-changers, input and output band filters, and voltage limiters. It occupies three bay faces, and is usually arranged on one face of a suite in order that the entire group equipment for the twelve channels shall be readily accessible for testing and lining-up when installing or re-routing.

The middle bay of the three carries the *receive* V.F. amplifiers and the 6 kc amplifiers. A test panel is fitted and to it are connected all the amplifier inputs and outputs. By means of U-links, any amplifier can be disconnected from its circuit for testing.

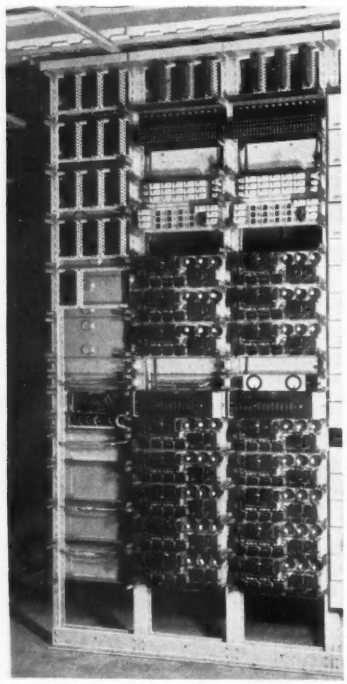


Fig. 7.—Duplicate generator bays and rear view of pilot bay, covers removed.

The other two bays carry the double frequency-changer panels and the input and output filters.

A test panel enables any double frequency-changer panel and its filter to be extracted from the circuits and tested.

GENERATOR EQUIPMENT.

The equipment under this heading consists of all the apparatus necessary to generate 6 kc and 22—66 kc for modulation and demodulation in the individual channels. The whole is mounted on the front and rear of one bay. Because of its importance the generator equipment is duplicated, the second set being mounted on a bay alongside the first, as shown in fig. 7. Between the two is the operating lever of a specially-designed switch. This is mounted at the top of the bays and is capable of changing over all the circuits from one bay to the other in one movement in which the transit time is less than 0.005 second. The high speed of this operation enables the spare bay to be substituted for the working bay without adverse effect on the service.

On the front of a generator bay are mounted the 1 kc driven oscillator, constant-volume amplifier, frequency doubler and harmonic generator panel, and five filter-amplifier panels, the other eight being fitted on the rear of the bay.

PILOT EQUIPMENT AND MASTER OSCILLATOR BAY.

This bay may carry a master oscillator, pilot transmitters and pilot receivers. The master oscillator comprises a valve-maintained tuning fork, which controls the oscillations of a valve system to a degree of accuracy of at least one part in 10^5. The fork, its driving coils, tuning condensers and output coils, are housed in a heavily-lagged box. This is maintained within narrow limits of temperature by means of heating elements that are controlled by a bridge which becomes unbalanced and allows the heaters to be switched on when the temperature falls.

The number of pilot transmitters fitted to the bay depends upon the number of routes it is desired to serve from the terminal. The bay will accommodate four, of which one is a spare. Provision is made also for a pilot receiver and a spare. A U-link panel enables the spare pilot transmitter to be substituted for a service transmitter, and permits the pilot receiver to be connected to any one of up to four routes over which the master frequency may be received.

LINE AMPLIFIERS.

Twelve-channel operation is to no small extent a problem of amplification of the sidebands, and it is largely due to the negative feed-back amplifier that the system has been made practicable. The amplifier designed specially for this system is capable of amplifying simultaneously all twelve sidebands without causing mutual interference. It has a gain of about 65 db and a response curve flat to within $\pm$ 0.1 db over the frequency range 10—70 kc. The gain is independent of usual variations in battery voltage and valve characteristics.

The gain is fixed, any necessary variations being obtained by means of the gain control panel, which comprises high-frequency attenuators adjustable in steps of 0.2 db between zero and 64.4 db.

A line-amplifier bay carries nine amplifiers (one of which is a spare) and their gain control panels, together with a test and change-over panel, which provides means for disconnecting a service amplifier

for test while it is replaced by a spare, the change-over time being no more than 5 milliseconds.

EQUALIZER BAY.

This bay carries the equalizers for the cable pairs. Each equalizer consists of two parts, a main and an auxiliary, the joint use of which equalizes line attenuation between adjacent stations so that the attenuation/frequency characteristic is flat to $\pm$ 4 db over the frequency range 12 to 60 kc. Between terminals, the observed limits are $\pm$ 2 db.

POWER PLANT.

The 12-channel carrier system requires the same power supplies as have for long been standardised for V.F. line repeaters, namely, 24 volts and 130 volts. Supplies to filament circuits are controlled at 21 volts $\pm$ 0.25 volts and to anode circuits at 130 volts $\pm$ 1.3 volts, usually by means of carbon-pile regulators. It should be noted that on the G.E.C. system this degree of control of anode voltage is not absolutely essential, a variation of $\pm$ 5 volts being permissible.

The various types of power plant that can be employed have in common the objective of absolute certainty in the continuity of supply. In large terminal or repeater stations, attended throughout or for the greater part of each twenty-four hours, the first endeavour is to obtain two independent mains supplies. Duplicate motor-generator sets and duplicate batteries for both anode and filament supplies are then installed. Batteries may be of large capacity and operated on a charge-discharge basis but an alternative and more modern practice is to employ batteries capable of carrying the station load for a comparatively short period, usually between two and six hours. The batteries serving the station are then floated whilst the others are trickle-charged, change-over from one set to the other being made at weekly intervals.

Should alternative mains supplies not be available at economic cost, then a standby oil-engine set is installed. This is capable of meeting the full station load, and at least one set of batteries has capacity for serving the station for twenty-four hours.

At unattended stations, with A.C. mains supply available, rectifiers are employed with floating batteries, the latter being capable of carrying the load for at least one hour. An oil-engine-generator set acts as a standby for charging the 24-volt and 130-volt batteries, the engine starting automatically in the event of mains failure.

Unattended stations served by a D.C. mains supply are equipped with a motor-generator set and an oil engine, which takes up the drive to the generators through a clutch, should the mains fail.

In the complete absence of a mains supply, two engines, two sets of generators and two battery sets are installed. The plant operates on a charge-discharge basis, the engines being brought into alternative use by means of a time switch, usually set to 48 hours. Failure of one engine automatically starts the other. An engine-generator set charging filament and anode batteries is automatically shut down when the batteries are fully charged. This is arranged by means of interlocked voltage relays. When, say, the 24-volt battery is fully charged its associated voltage relay introduces a limiting resistance into the charging circuit until, when the 130-volt battery is fully charged, the second voltage relay operates to stop the engine. Such a station as this is visited usually every fourteen days.

ALARMS.

Alarms are given in the event of the development of faults in the equipment. They are divided into two categories, urgent: which require prompt attention, and non-urgent: attention to which may be deferred. Alarms at unattended stations are

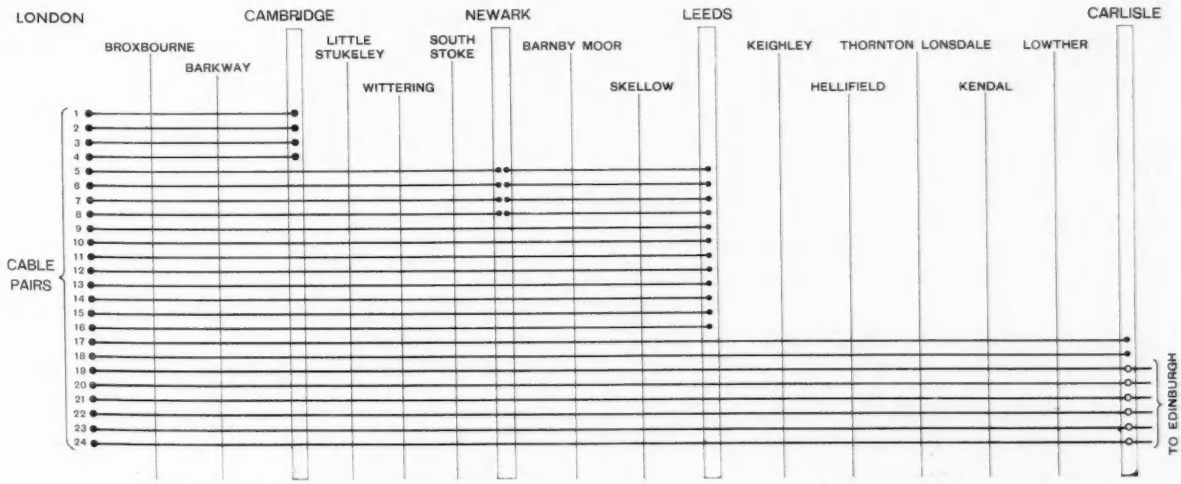


Fig. 8.—Allocation of cable pairs (London—Cambridge—Newark—Leeds—Carlisle circuits).

extended over phantom circuits on the cable pairs to attended stations.

THE LONDON-CARLISLE CIRCUITS.

The circuits that run from London, through Cambridge, Newark, and Leeds, to Carlisle form a backbone for the nation's trunk system. The cable throughout is of Pirelli-General manufacture, and equipment is installed or in course of installation to provide four groups of twelve channels between London and Cambridge, four between London and Newark, eight between London and Leeds, and eight between London and Carlisle. In addition, there are to be four groups between Newark and Leeds. This allocation of the cable pairs is shown in fig. 8.

Fig. 9.—Temporary huts for intermediate repeater station equipment at Little Stukeley.

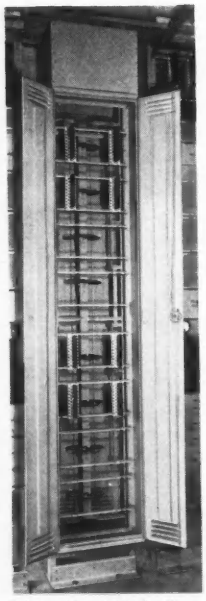


Fig. 10.—High frequency distribution frame, partially equipped.

The terminated circuits may be cross-connected as necessary at Leeds to other circuits, including those of the 12-channel type between Leeds and Derby, and Leeds and Manchester, for which equipment is in production. At Carlisle, the circuits will be extended as desired to Glasgow, Edinburgh, Dundee and Aberdeen.

The total route distance, London to Carlisle, is 315 miles, with repeater stations at an approximate average of 20 miles. Cambridge, Newark and Leeds, in addition to being terminals, are equipped as repeater stations for the through circuits. Other repeater stations are unattended, and are installed at points shown in fig. 8. Temporary accommodation for these repeater stations has been provided by huts erected generally to the rear of the sites to be occupied by the permanent buildings. Three huts at each point (fig. 9) accommodate line amplifiers and equalisers, batteries, and charging plant respectively.

Small departures from symmetry, inevitable in the construction of the cables, may give rise to cross-talk greater than could be tolerated. Such inequalities are balanced out by connecting small variable condenser units between each pair and every other pair in the cable. These units, mounted in special cabinets, were formerly fitted at approximately the mid-point of each repeatered section. It has recently been found possible to fit them at the ends of the section in the repeater stations themselves, thus rendering unnecessary the provision of the small buildings in which they were previously housed.

A feature of the 12-channel system is its flexibility. For example, the allocation shown in fig. 8 is by no means rigid. It requires only that terminal equipment at, say, Cambridge, be moved to, say, Newark, and replaced by amplifiers, for Newark to have an increased number of circuits to London. The greatest degree of flexibility, however, is given by the ability to cross-connect circuits at the principal stations. This cross-connection can be made at carrier frequency in order that one set of 12-channel circuits may be switched to another without the need for reducing the circuits to voice frequency. Such cross-connexion is made at the high-frequency distribution frame (H.F.D.F.). A partially-equipped H.F.D.F. is shown in fig. 10.

Consider the Leeds station, where a number of 12-channel routes intersect and it may be desired to

cross-connect them. In fig. 11, the routes are numbered 1, 2 and 3, and their *transmit* and *receive* cables, the latter including amplifiers and equalisers, are shown on the right of the diagram. On the left is the equipment in the twelve groups each of twelve channels that are terminated at Leeds. Simple cross connections on the H.F.D.F., made as shown, enable any route to be terminated on the Leeds equipment or to be connected to another route to form a through-circuit.

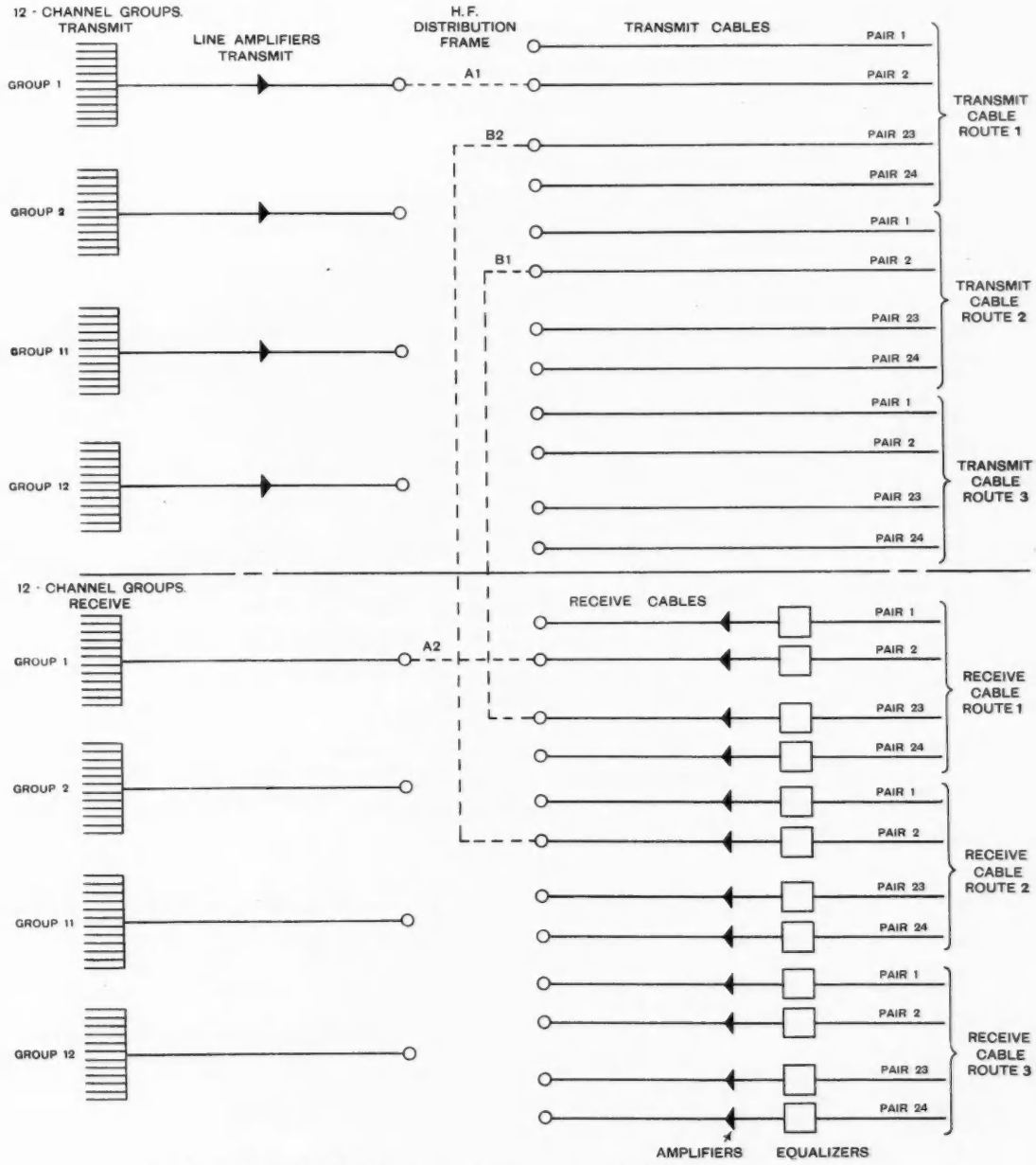


Fig. 11.—Allocation of circuits on high frequency distribution frame. A1, A2—terminated circuits; B1, B2—through circuits.

High-Frequency Electric Melting Furnaces.

Fig. 1.—Pouring into moulds from hand shanks in the melting shop at Brockhouse Castings, Ltd.

AN INSTALLATION AT BROCKHOUSE CASTINGS LTD., : WEDNESFIELD, : WOLVERHAMPTON.

By S. EVANS, M.Sc.,
General Manager,
Brockhouse Castings, Ltd.

THE Brockhouse organization in recent years has expanded very considerably, not only in size, but in the variety of products manufactured by its subsidiaries. The parent firm, J. Brockhouse & Co., Ltd., was founded in 1886, and the head office as well as the largest factory are situated in West Bromwich. Although the majority of subsidiary companies are to be found in the Midlands, the group owns works as far afield as Glasgow, Southport and London.

The factory at Wednesfield was taken over three years ago. At that time the sole product was white porcelain enamelled cast iron baths, which were hand moulded. Since then, the factory has been completely re-built, machine moulding introduced and an entirely new enamelling shop erected, with the result that this works is now one of the most modern in the country.

On an adjoining site a new steel foundry has been erected and equipped with the most up-to-date electric furnaces of both the high-frequency induction type and the arc type.

Fig. 2.—Pouring from the 10-cwt. high-frequency electric melting furnace.

The high-frequency electric melting furnaces were manufactured and installed by The General Electric Co., Ltd., whose experience in the design of this class of equipment and knowledge of foundry and steel making practice have suggested many improvements towards simplicity of operation and greater efficiency.

This works has thus established itself as an

important unit in the organization, since it goes far towards rendering the group self-contained in the matter of steel castings and tool steel, besides catering for the engineering trades in general.

Other products include heat resisting steels, magnet steels and a wide range of special alloys of high melting points.

ADVANTAGES OF HIGH-FREQUENCY MELTING.

The metallurgical advantages of the high-frequency electric melting furnace are now sufficiently well known to render it unnecessary to do more than enumerate the more important of them, which are: accurate pre-determination of the composition of the product; absolute cleanliness and freedom from adventitious addition of carbon, sulphur or other undesirable elements; exceptional uniformity in composition, whether of castings or ingots, owing to the stirring effect which is peculiar to this type of furnace. Another advantage is that the temperature of the molten metal can be regulated more easily than in other types of melting furnace. Moreover, the temperature can be varied quite rapidly from the higher range required for small castings poured from hand shanks, to the comparatively low range necessary for pouring ingots from the ladle. In fact, in the foundry at Wednesfield, it is not unusual for the first half of a melt to be hand shanked to castings, and for the second half to be either ladle poured or hand shanked to ingot moulds within a minute or two of the completion of the pouring of the first half of the melt. Fig. 1 illustrates the pouring from hand shanks into moulds, while fig. 2 shows a charge being poured from the 10-cwt. furnace.

Experience has shown that this type of furnace is particularly suitable for the manufacture of high-grade alloy steel castings and, in fact, of a very wide range of both ferrous and non-ferrous alloys having high pouring temperatures. By a proper selection of raw materials it is possible to melt with a negligible carbon and silicon loss.

The linings of these furnaces have a very long life which is largely determined by the precautions taken to protect them. For certain alloys basic linings are used, but, in general, acid linings are satisfactory for nearly every purpose and a very wide range of compositions can be produced from the one furnace.

It has been generally accepted that refining does not take place in the high-frequency furnace; this is not strictly true as a certain amount of refining can, and actually does, occur. Normally, however, this refining is not necessary as, after a little experience, the technician can predict the final composition of his melt with great accuracy.

On account of the low thermal capacity of the linings, it has been found quite practicable, both as regards convenience and economy, to use individual furnaces intermittently and to change from one size to another as circumstances require. The change-over is a matter of minutes only, and the increase in current consumption per unit of output on this account is less than with any other type of furnace.

The G.E.C. high-frequency furnace was chosen for this installation because it is of the partially cored type which possesses many advantages. Partly due to improvements in design and partly to the fact that these furnaces are now thoroughly understood, the maintenance charges on them are quite low. The plant at Wednesfield has now been in full commercial operation for a period of ten months and has proved thoroughly satisfactory. Experience has shown that the various advantages enumerated above combine to render this type of furnace very economical.

CONSTRUCTION OF THE HIGH-FREQUENCY FURNACES.

For this installation three high-frequency furnaces have been supplied of 10-cwt., 5-cwt. and 3-cwt. capacity respectively. They were designed and built at the Witton Engineering Works

Fig. 3.—View of the foundry showing, in the background, the high-frequency furnaces, furnace control panel, collecting tank and hydraulic accumulator.

in accordance with the Stobie patents, as described in detail in previous issues.[1] The 10-cwt. furnace is arranged for operation alone, while the two smaller ones can be operated either individually or together.

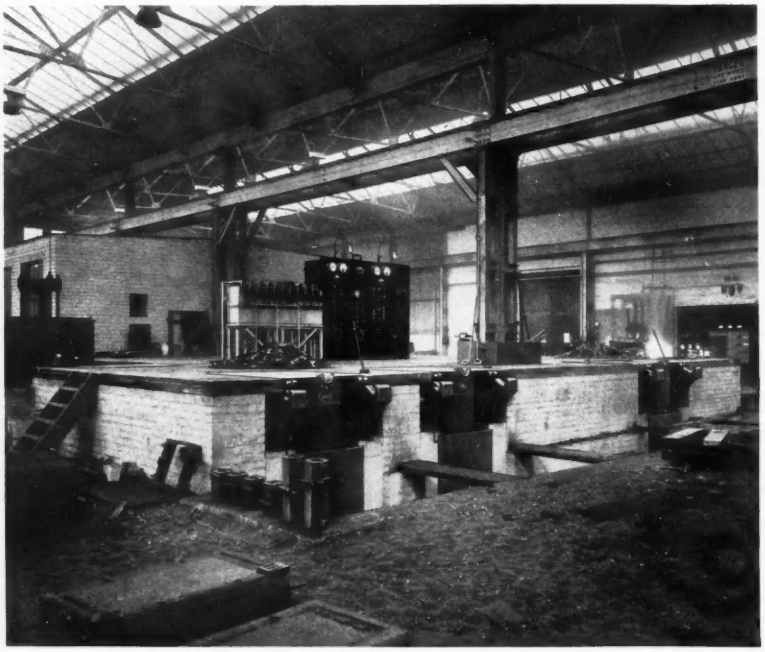


Fig. 4.—General view of 3-cwt., 5-cwt., and 10-cwt. high-frequency electric melting furnaces.

Each furnace consists essentially of a strong steel casing containing the inductor coil, its laminated steel magnetic circuit and a refractory lining. The inductor coil, which is water cooled, is built up of a number of turns of copper tube wound in sections and connected in series, each section being formed of a single length of tube without joints. For the 10-cwt. furnace four sections are employed, while the two smaller furnaces have three sections each. Cooling water is supplied independently to each section, thus maintaining an adequate pressure head to enable sufficient water to be supplied to the inductor. By this means, also, individual regulation is possible and any local overheating or a stoppage in any section is immediately indicated by the operation of the thermostats or water-flow relays.

The copper turns of the inductor coil are heavily insulated with mica-silk tape which is further protected by a wrapping of asbestos tape impregnated with a moisture-proof insulating compound. The outer protection serves the double purpose of partial heat insulation and of rendering the coil mechanically stronger. This method of insulating prevents the condensation of moisture on the copper tube and serves to maintain the insulation itself at a low temperature, despite the high temperature gradient between the charge and the copper inductor coil.

Heavy copper strip is employed to connect the inductor to the isolating plugs at the base of the furnace through which the high-frequency supply enters. The use of isolating plugs in place of flexible leads ensures an exceptionally rigid construction.

The inductor coil is surrounded and supported by a four-part magnetic circuit constructed of high permeability silicon steel laminations. This external core serves to raise the inherent power factor, to improve the coupling between the coil and charge, to prevent the external magnetic field from reaching neighbouring ironwork and to provide a rigid mechanical support for the inductor and crucible.

FURNACE COOLING SYSTEM.

It is necessary to provide some means of preserving the inductor insulation from damage due to heat, part of which is received by conduction from the charge through the refractory lining, and part generated in the inductor coil itself by the passage of the high-frequency load current. Therefore, as already indicated, cooling water is circulated through the inductor coils.

A two-stage centrifugal pump, driven by an electric motor, draws cold water from an outdoor storage tank and delivers it to the various sections of the inductor coil which are fed in parallel. The water passes to and from the coils through rubber hose which possesses sufficient flexibility to allow the furnace to be tilted without breaking the flow, and also serves to insulate the parallel water paths from one another and from earth. After passing through the furnace the water is taken through thermostats and over water-flow relays to a collecting tank on the furnace platform and thence back to the storage tank. A total quantity of 1,500 gallons of water an hour can be supplied.

TILTING.

The furnace has a lip, or spout, at the front for pouring, and is fitted with double trunnions at the sides. The tilting gear is hydraulically operated, the movement being effected by means of ropes attached to a boom actuated by a hydraulic ram. Tilting is controlled by a handle on the furnace platform attached to a valve mounted below, by

1. G.E.C. Journal, Vol. III., Nos. 2 and 4, Nov. 1932; Vol. VII., No. 2, May, 1936.

means of which varying speeds can be obtained. At the beginning of the tilt the furnace swings forward rapidly on the lower pair of trunnions, while towards the end the upper pair engage and the furnace is tilted about an axis roughly coincident with the spout. In this way the operation of pouring can be controlled with great precision, and there is little risk of the charge being spilt. To prevent over tilting, stops are provided on the ram to limit its stroke as soon as the fully tilted position is reached.

By means of an interlock the high-frequency supply to the furnace is cut off immediately tilting begins.

Water at a pressure of 1,500 lbs. per sq. in. is used for the hydraulic operation and is obtained from an accumulator charged by a single-ram pump driven by an electric motor.

LAYOUT.

Fig. 3 gives a general view of the foundry in which the three furnaces are installed, while a near view of the furnaces, control panel and collecting tank is seen in fig. 4. The tilting gear is directly below the furnaces, the hydraulic accumulator is shown on the left, while the motor-alternator set, fig. 5, is housed in a separate substation. In a brick built chamber situated behind and below the furnace platform, are accommodated the banks of fixed and variable condensers and associated contactor gear, the generator panel, auxiliary contactor and relay panel, the auto-transformer, the furnace selection switches and the motor-driven ram pump for the hydraulic accumulator. Views of the condenser banks and the relay panel are shown in figs. 6 and 7 respectively.

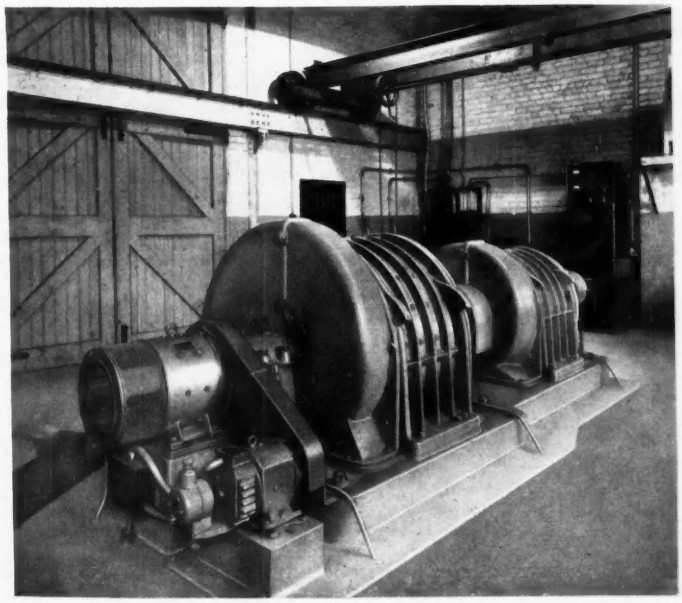


Fig. 5.—High-frequency motor-alternator set in the sub-station.

ELECTRICAL EQUIPMENT.

The 10-cwt. high-frequency furnace is rated at 400 kW and designed for a voltage of 2000. It is

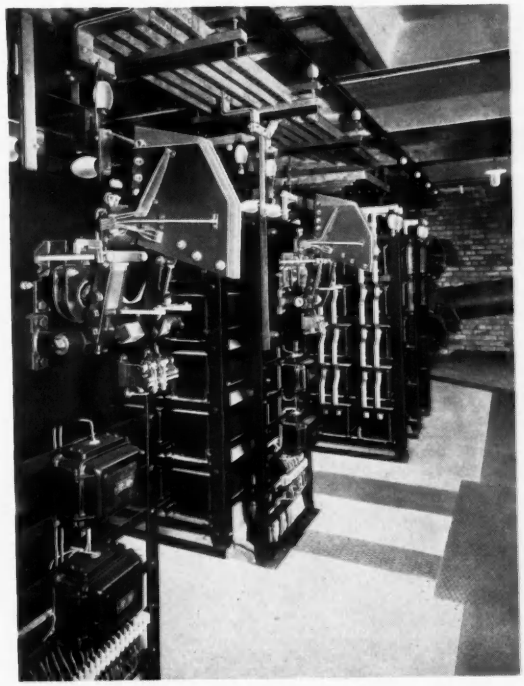


Fig. 6.—Banks of fixed and variable condensers and contactor gear.

specified to melt and cast 10-cwt. in one hour and to produce 3 tons per 8 hour shift, an output that, in fact, was easily attained.

The 5-cwt. and the 3-cwt. furnace are arranged for individual or simultaneous operation from the same high-frequency alternator and condenser bank. For convenience in the condenser switching circuits, it was decided that these furnaces should be designed for 1000 volts and the 10-cwt. furnace for 2000 volts, the frequency in all cases being 1000 cycles.

In addition to the furnaces the main items of electrical equipment are as given below :—

(1) A 400 kW motor-alternator set to provide single-phase current at 2000/1000 volts, 1000 cycles, for supplying the high-frequency furnaces.
(2) 7000/400 volt transformer, Scott connected 2/3 phase, 50 cycles, for supplying the motor-alternator set and auxiliaries.
(3) 110 kVA static condenser, 400 volts, 50 cycles, 3 phase, for power factor correction of the motor driving the high-frequency alternator.

(4) Banks of fixed and variable condensers for power factor correction of the high-frequency system.

(5) Control gear, including (*a*) switchgear for the low tension side of the main trans-

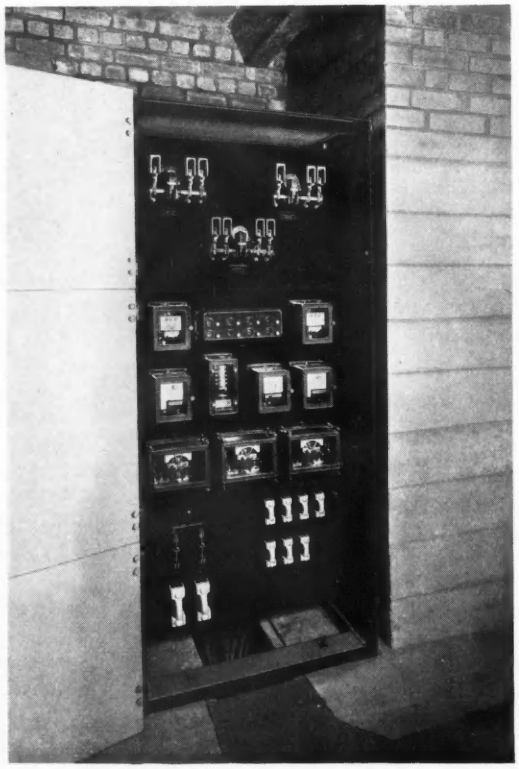


Fig. 7.—Auxiliary contactor and relay panel in the condenser room.

former and control of the motor of the motor-alternator set; (*b*) furnace control board consisting of four panels, one for each furnace and one for controlling the pumps, etc.; (*c*) relay panel, carrying the protective relays and sequence contactors; (*d*) generator panel for controlling the high-frequency supply to the furnaces; this panel also carries the series-parallel change-over switches for connecting the alternator windings; (*e*) a change-over switch for furnace selection. The 10-cwt. furnace is used alone, while the 3-cwt. and 5-cwt. furnaces can be operated together or individually.

(6) Electrically driven pump for circulating the cooling water through the furnace inductor coils; (*b*) electrically driven single-ram pump for maintaining the required pressure in the hydraulic accumulator for operation of the tilting gear; (*c*) a motor driven fan for forced ventilation of the condenser room and substation.

MOTOR-ALTERNATOR.

The generating unit consists of a high-frequency alternator of special design, directly coupled to a slipring induction motor of standard construction. The machines are mounted on a combined bedplate, there being three main pedestal bearings fitted with phosphor-bronze bushes and arranged for water cooling.

The high-frequency supply is at 1000 cycles and a salient pole type of alternator has been adopted, there being 80 poles on the rotor which is driven at a synchronous speed of 1500 r.p.m. Each alternate pole is provided with an exciting coil constructed of flat copper strip with asbestos interleaves between turns, mica slot lining being used to insulate the complete coil from the rotor body. By this mode of construction it has been possible to produce a high-frequency alternator with 80 salient poles, using only 40 exciting coils.

To hold the rotor coils in place under the high centrifugal stress to which they are subjected, duralumin wedges are used on the core portion and high tensile bronze caps on the free overhang. Between the slot wedges and the exciting coils a damping winding is arranged to relieve the junction of end bells and wedges from damage due to damping currents which are always present in single-phase stator windings.

The rotor shaft is made of non-magnetic steel so that any unbalance in the field due to the use of one exciting coil per pair of poles does not lead to bearing troubles.

The stator of the alternator is built up of thin silicon steel core plates varnished on both sides, the core clampings rings being of bronze to minimize stray load losses as far as possible.

The stator winding is arranged in two circuits so that by appropriate interconnection of the terminal leads either a 1000 volt or a 2000 volt supply can be obtained. Further to minimize eddy current losses stranded conductors are used for the stator winding, which is so arranged that the number of sweated joints is kept as small as possible.

In order to reduce windage noise to a minimum, both generator and motor are arranged for pure axial ventilation. In each case air is drawn from one end of the substation and ejected at the other by the fan through air trunks in the foundations and thence outside the substation. The incoming air is passed through a viscous-type filter so as to remove any suspended impurities.

As a further precaution against noise the overhanging portions of the rotor coils are enclosed in smooth bronze end covers, while the surface of the rotor core, together with the slot wedges, is given a smooth cylindrical finish.

The alternator, which is rated at 400 kW

2000/1000 volts, 1000 cycles, single-phase, is excited by a 13·3 kW 140 volt compound wound exciter coupled direct to the alternator shaft. There is also a pilot exciter belt driven from the main shaft and rated at 320 volts, 2·25 amps. Two exciters are used so as to secure very rapid regulation of the high-frequency supply voltage.

The motor is a standard 650 h.p. slipring machine running on a 400 volt, 50 cycle, 3-phase supply, fitted with a brush raising and short circuiting device, and hand started by means of a liquid starter. It is supplied from the low tension side of the Scott-connected transformer and controlled by an oil switch housed in a sheet steel cubicle. A static condenser is permanently connected in circuit so as to maintain the power factor above 0·95 lagging under all conditions of load.

HIGH-FREQUENCY CONDENSER EQUIPMENT.

Although the inherent power factor of the Witton high-frequency furnace is higher than that of other furnaces of similar general type, it is expedient to provide condensers to maintain the high-frequency system in the neighbourhood of unity power factor.

There is a bank of fixed condensers permanently connected in circuit, but in order to meet the changing conditions during the process of melting it is necessary to be able to vary the condenser capacity over a wide range, for which reason four banks of variable condensers are employed. To simplify the connections when the two smaller furnaces are working simultaneously, each bank is divided into two equal parts suitable for 1000 volts and operated independently with one of the furnaces. When the 10-cwt. furnace is in use the two parts are connected in series for service at 2000 volts.

The condensers consist of a number of naturally cooled unit boxes, containing oil immersed condenser spools of special design for high-frequency service.

The condenser room, which is situated below ground, is cooled by means of a fan. The air passes through a filter and is directed onto the condenser

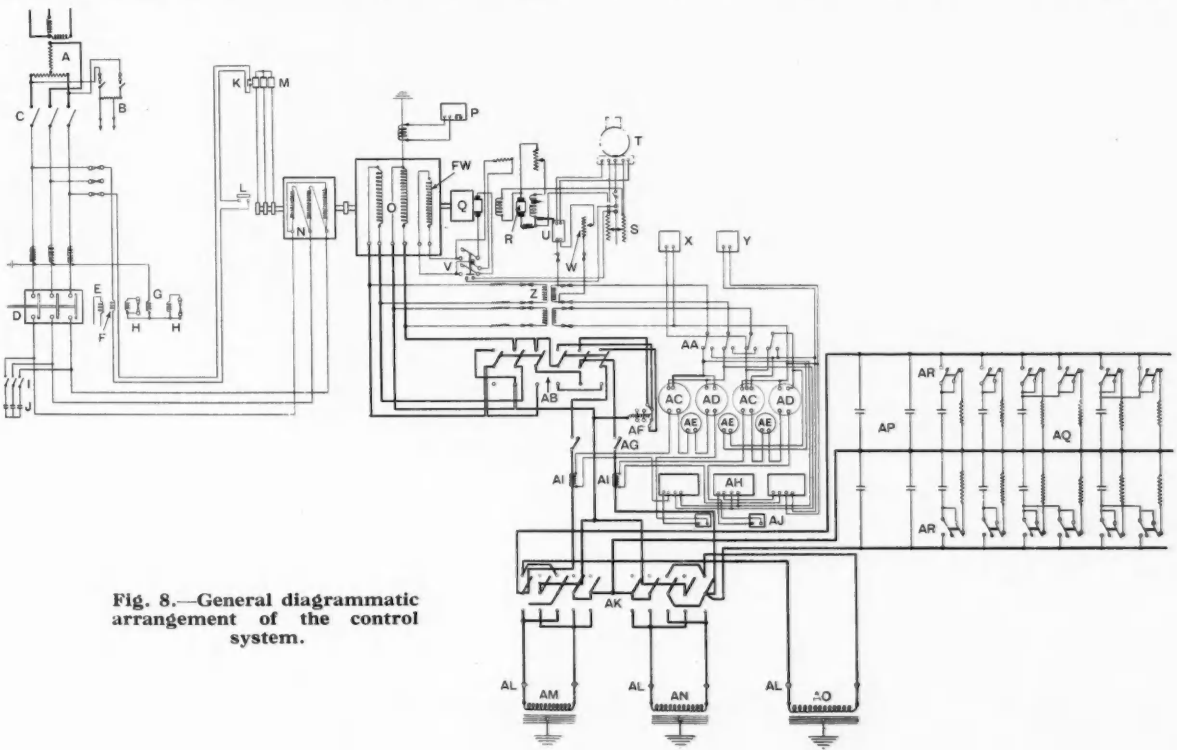


Fig. 8.—General diagrammatic arrangement of the control system.

KEY.

A	Scott connected transformer.
B	Auxiliary transformer for 230 volt operating supply.
C	Isolating Links.
D	Main oil switch.
E	Undervoltage relay.
F	Interlock coil.
G	Earth leakage relay.
H	Overload trips with time limit fuses.
I	Motor Condenser switch.
J	Motor Condenser Bank.
K	Interlock on motor starter.
L	Interlock on brush lifting device.
M	Liquid starter for main motor.
N	Main motor.
O	H.F. single-phase alternator.
P	Earth leakage relay.
Q	Main exciter.
R	Pilot exciter.
S	Exciter field rheostat.
T	Isenthal voltage regulator.
U	Metallic rectifier.
V	Alternator field contactor.
W	Ballast resistance.
X	Overvoltage relay for 3 cwt. furnace.
Y	Overvoltage relay for 5 or 10 cwt. furnace.
Z	Two single-phase H.F. potential transformers.
AA	Furnace changeover switch.
AB	Series-parallel changeover switch.
AC	Power factor meter.
AD	Wattmeter.
AE	Ammeter.
AF	Autotransformer.
AG	Main generator contactors (H.F. circuits).
AH	Power factor alarm relays.
AI	Current transformers for indicating instruments and protective relays.
AJ	Overload relays.
AK	Changeover switch for furnace selection.
AL	Isolating plugs.
AM	3-cwt. furnace.
AN	5-cwt. furnace.
AO	10-cwt. furnace.
AP	Fixed Bank of coudensers.
AQ	Variable Bank of Condensers.
AR	Contactors for variable Banks of condensers.
FW	Alternator field Winding.

banks by means of ducts situated directly beneath. The fan motor is remote controlled from the furnace platform, and an interlock on the starter ensures that the fan is running before power can be switched onto the furnaces.

INDEPENDENT LOAD CONTROL OF FURNACES.

For efficient operation of the furnaces and for satisfactory control of the charge temperature, it is important that there should be rapid regulation of the high-frequency voltage, that is, a quick response of the field strength to the position of the field rheostat. This is achieved by the use of a main and a pilot exciter, together with an automatic voltage regulator connected to the field systems.

When the two smaller furnaces are operating at the same time, however, it is obviously not possible to control the voltage applied to one without interfering with the working of the other. The automatic voltage regulator is therefore put in operation to maintain the alternator voltage constant, while the load on either furnace can be reduced independently of the other by connecting it to suitable voltage tappings on an air cooled autotransformer.

CONTROL SCHEME.

A diagrammatic arrangement of the various power circuits is shown in fig. 8.

The 400 volt, 3 phase supply from the low tension side of the main transformer is brought to a sheet steel cubicle equipped with isolating links and an oil circuit breaker which controls the induction motor of the motor-alternator set.

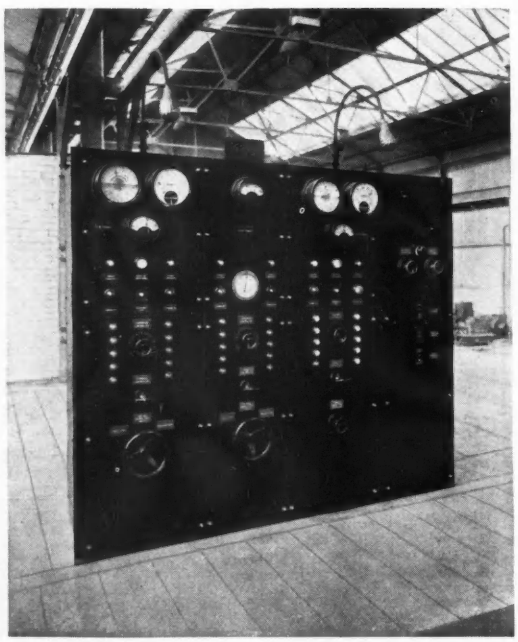


Fig. 9.—Furnace control panel for the 10-cwt., 5-cwt. and 3-cwt. high-frequency furnaces.

A tapping from the 400 volt supply is taken to an ironclad switch fuse for energising a small 20 kVA 400/230 volt transformer which feeds the auxiliaries and operating circuits.

It should be noted that the centre point of the alternator winding is earthed through a current transformer and that the iron cores of the furnaces are also earthed.

Reference to the diagram shows that the alternator windings are in two halves which may be connected either in series or parallel so as to give a 2000 volt or a 1000 volt supply respectively, according as the 10-cwt. furnace or the two smaller ones are being operated. The windings are connected as desired by means of two triple-pole hand-operated changeover switches, mounted on the lower half of the generator panel. The upper half of the panel carries two single-pole generator contactors. When the 10-cwt. furnace is required both poles operate together, when the 5-cwt and 3-cwt. furnaces are to be used each is controlled by one single-pole contactor.

A furnace selection switch, consisting of a set of ten single-pole hand-operated changeover switches, is provided for connecting the high-frequency power supply and condenser banks either to the 10-cwt. furnace or to the 5-cwt. and 3-cwt. furnaces.

Control of the high-frequency circuits, the furnaces and auxiliaries is effected from the furnace control panel, fig. 9, which is mounted on the furnace platform and contains the following equipment :

(1) 3-cwt. furnace panel: A power factor meter, wattmeter and ammeter, emergency push button and indicating lamps to give the following indications :—
   (*a*) Furnace selector switches correctly closed.
   (*b*) Condenser change lamp, operated from the reactive kVA relays, indicating that the power factor has fallen below 0·95 lagging or leading, necessitating a change in condenser capacity.
   (*c*) High-frequency power "on" and "off" the furnace.
   (*d*) Main motor oil circuit breaker closed.

   In addition, the 10-step hand operated condenser controller and indicating lamps are mounted on this panel together with the main control key for closing the generator contactors. At the bottom is mounted the auto-transformer tapping switch.

(2) 5-cwt. furnace panel : The voltmeter mounted on the panel indicates for all three furnaces. The meters for the 5-cwt. furnace are mounted on the 10-cwt. panel and are used for the two furnaces by changing over the potential transformer connections.

   The remaining equipment on this panel is

the same as that on the 3-cwt. panel, with the addition of an indicating pressure gauge for use with the hydraulic tilting gear.

(3) 10-cwt. furnace panel: The apparatus on this panel is similar to that on the 3-cwt. panel except that the furnace changeover controller is mounted in place of the auto-transformer tapping switch.

(4) The fourth panel carries the main exciter field regulator, the ballast resistance for the Isenthal auto-voltage regulator and a tumbler switch for rendering the voltage regulating relay inoperative.

There are three sets of push buttons for controlling the following :—

(*a*) Motor driving cooling water pump.
(*b*) Motor driving hydraulic ram pump.
(*c*) Motor driving condenser room fan.

To set the furnaces in operation the main and auxiliary transformers are energised, and the cooling water circulating pump and the fans for the condenser room and substation are started up by push buttons on the surface control panel.

The changeover switches on the generator panel are set either in the series or parallel position and the furnace selection switches closed so as to connect the appropriate furnace, or furnaces, to the high-frequency supply, after which the doors of the condenser and furnace tilting rooms are closed and latched. The provision of interlocks in the running sequence ensures that all these operations must be correctly performed before the high-frequency power can be switched on. The oil switch controlling the main motor is then closed and the motor-alternator set started by hand in the usual way.

To connect the furnaces to the high-frequency supply the contactors on the generator panel are closed by means of the appropriate control keys on the furnace control panel, the 3-cwt. and 5-cwt. unit each being controlled by one single-pole contactor while for the 10-cwt. furnace both contactors are closed.

PROTECTIVE FEATURES.

The plant is completely protected against faults which may occur on it or on the system to which it is connected. The following list briefly summarizes the protective features :—

(*a*) Emergency stop buttons, one for each furnace panel, to shut down the motor-alternator set, if necessary.
(*b*) Over voltage protection for the high-frequency supply circuits of the 10-cwt., 5-cwt. and 3-cwt. furnaces.
(*c*) Earth leakage protection for the high-frequency circuits.
(*d*) Over current protection for the high-frequency circuits.
(*e*) Over temperature of the inductor coils.
(*f*) No-volt protection (incoming supply).
(*g*) Overload protection (incoming supply).
(*h*) Limit switches for furnace tilting.
(*k*) Overload, etc., on auxiliary motors.
(*l*) Incorrect operation of the control panel.

It will be understood that in addition to the protective devices here listed, the comprehensive system of sequence interlocking already described serves either to prevent incorrect sequence of operation or to shut down the plant should an error be made.

A Note on the Operation of the Periodically Ignited Mercury-Pool Rectifier.

By D. G. PRINZ, Ph.D.,
G.E.C. Research Laboratories, Wembley, England.

RECENT publications[1] show that considerable interest still exists in the development of methods for the control of single-phase mercury-pool rectifiers employing a much smaller controlling power than is normally made use of for polyphase arrangements. This fact may justify the brief publication of some experiments carried out by the author during the past year.

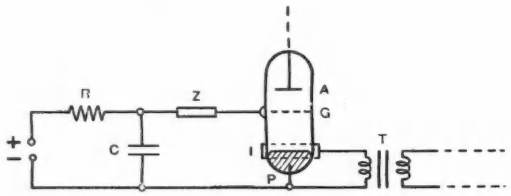


Fig. 1.

The present note deals only with circuits employing an ignition impulse, acting periodically upon the pool cathode, and an additional controlling device, capable of preventing the anode discharge notwithstanding the ignition of the cathode spot.

The ignition method used in the experiments is that first employed by Cooper-Hewitt more than thirty years ago: namely, the application of high-voltage impulses to an external electrode attached to the glass wall and surrounding the edge of the mercury pool, commonly known as a "starting band."

The most obvious way to withhold the anode current is to insert a negatively charged grid between cathode and anode. Whilst in a polyphase rectifier a negative grid collects ions from the exciter arc and from the discharges to the other anodes during the whole period, the grid current in a periodically ignited single-phase valve is zero at the moment of ignition, thus permitting a grid voltage source of very high resistance, that is a very low controlling power. This resistance is, however, limited by the positive potential which the grid may attain due to its coupling to the anode and the ignition electrode, either through leakage resistance or capacity. Also, the effects of glass wall charges, especially noticeable when employing the Cooper-Hewitt method of ignition, tend to make this method of control rather unreliable. Furthermore, the grid must be so designed as to allow anode current to flow at zero grid potential for the instantaneous anode voltage at the moment of ignition, for in the alternative arrangement (where the grid is designed so that it is necessary for a positive voltage to be applied to it before anode current can start) it has been found that a grid voltage source of very high internal resistance will not initiate the main discharge. Only if the resistance of the voltage source is low enough to supply a grid current of at least some 10 mA. will the cathode spot be maintained long enough to allow the main discharge to be formed.

The fact, however, that a duration of a few microseconds is sufficient for this purpose again points to the possibility of a circuit requiring a much smaller

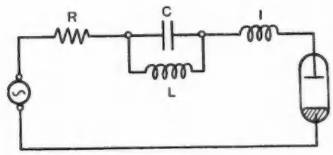


Fig. 2.

controlling current; for the average current supplied by the voltage source can be much smaller than the current required for keeping the spot alive.

A circuit realising this idea is shown in Fig. 1. The mercury pool *P* is provided with an external ignition electrode *I* connected to the high voltage ignition transformer *T*. The main circuit connected to the anode *A* is not shown. The grid *G* is in this case so constructed that it normally prevents the flow of anode current at zero grid potential.

An auxiliary circuit consists of a condenser *C* charged up from a D.C. supply through a high resistance *R* ("hard" valve, photoelectric cell). When the cathode spot is formed, this condenser will be discharged through the impedance *Z* into the grid *G* which then acts as a kind of auxiliary anode keeping the spot alive until the arc is transferred to the main anode. If, for instance, the condenser *C* has a capacity of ·001 μF and is charged up to 100 volts it will be able to supply an average current of 20

1. Y. Watanabe and H. Kasahara, B-Type Sendytron using a New Method of Starting Mercury Arc. E.T.J., 2, 11, p.253, 1938.

milliamps. for a time of 5 microseconds which is sufficient to start the main discharge. On the other hand, a current of only 10 microamps. is needed to charge the condenser up to 100 volts within half a cycle (10 milliseconds), and a device, capable of handling 10 microamps, put in the place of R, will therefore be able to control the rectifier.

An entirely different way of suppressing the discharge is shown in fig. 2; the method of operation is to control the way in which anode current will build up by virtue of the external anode circuit. R is the load resistance, L an inductance, large compared with the inductance l, and the natural frequency of the oscillatory circuit formed by the inductance l and the condenser C is high compared with the frequency of the supply. We can then assume that the instantaneous voltage of the A.C. source at the moment of ignition, say E, remains constant during the whole process to be described. The current flowing through the valve after the anode spot has been ignited can in these circumstances be regarded as consisting of two components: one determined mainly by L, rising linearly at a rate given by the equation $E = L\,di/dt$, and another, caused by the condenser C being charged through the valve, oscillatory with a frequency and damping determined mainly by C, l and R.

If the valve could pass current in both directions the resulting wave form would have the appearance shown in fig. 4a. Actually, however, the cathode spot will die out as soon as the current reaches zero, and the whole oscillation will be reduced to a single

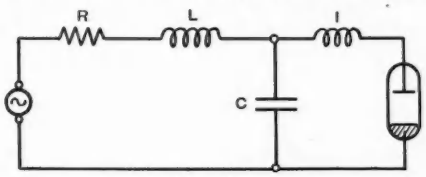


Fig. 3.

half-cycle of the oscillatory frequency, as shown in fig. 4b. Since the duration of this pulse is usually only of the order of microseconds, the resulting mean current will be so small as compared with the normal current of the rectifier that the discharge can be regarded as completely suppressed.

It is obvious that this effect can be used for controlling the discharge by adding an auxiliary circuit of the type shown in fig. 1, capable of keeping the cathode spot alive until the main current again attains a positive value. A special advantage may here be seen in the fact that the auxiliary electrode need not have the shape and the properties of a control grid but may for instance merely consist in a thin wire sealed through the envelope at some convenient place between cathode and anode; for the duty of suppressing the discharge now rests with the circuit itself, and the load to be dissipated by the auxiliary electrode is negligibly small.

Furthermore, the principle enunciated permits the use of still other methods of control; for if the ratio L/l is below a certain critical value[2] or if, at a larger ratio L/l, the damping of the lCR circuit exceeds a certain amount, the resulting current will not reach zero at all, and the discharge will not be

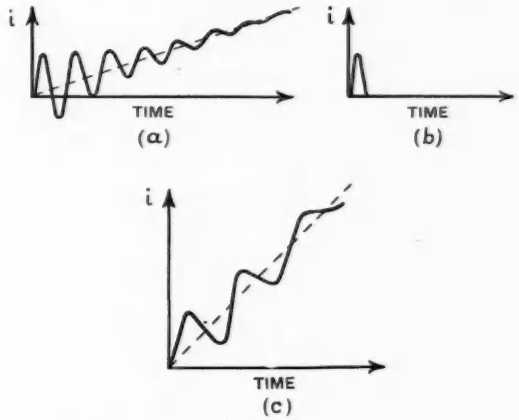


Fig. 4.

suppressed (fig. 4c). Therefore, control of current can be brought about by any means that will affect the values of L, l, or the damping, or a suitable combination thereof in such a manner as to change the wave form of the valve current from the type shown in fig. 4b to that shown in fig. 4c.

As an example of the application of this principle, there is shown a circuit designed for automatic interruption in the case of overload or short-circuit, without any relays, switches or additional valves (fig. 5).

The A.C. source, the inductance of which is shunted by a condenser C_1, feeds a circuit of the type shown in fig. 2, the values of R, l and C_2 being such as to suppress any oscillation in the RlC_2 circuit ($R \geq 2\sqrt{l/C_2}$). Thus the discharge will take place in the normal way. If, however, the value of R is

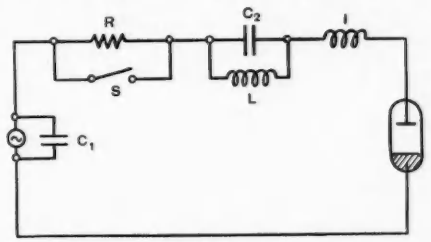


Fig. 5.

reduced to zero by a short-circuit in the load, as indicated by the switch S, the damping will practically disappear, oscillations will occur, and the current will be reduced to a negligibly small fraction of the value it had before the short-circuit intervened.

As an alternative to the circuit given in fig. 2, the

2 For the case of no damping, this value is 4.6/1.

condenser C may be connected across the valve, as shown in fig. 3. In this case, C is charged from the A.C. supply and discharged through the valve, the wave form of the current being essentially the same as in the previous case.[3] The circuit of fig. 2 would appear preferable, however, since in practice the distributed capacity of the inductance L will be noticeable in any case. It may even so happen that a single coil inserted in the anode circuit will suffice to suppress the discharge. This may be explained by assuming the distributed capacity to be in parallel with the greater part of the coil, forming the inductance L, whilst the remaining part, the capacity of which can be neglected, serves as inductance l.

In a practical case, the leakage inductance and distributed capacity of the main transformer itself might thus prevent a proper operation of the rectifier. By inserting additional inductances, thus improving the L/l ratio, preferably in combination with means for damping the oscillations, it will often be possible to restore reliable ignition.

3 The damping caused by the load will, however, be modified in this case.

Technical Literature.

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE STAFF OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

THE MEASUREMENT OF SECONDARY EMISSION IN VALVES.*

By L. R. G. Treloar (The M.O. Valve Co. and the G.E.C. Research Laboratories).

Wireless Engineer, XV, p. 535, October, 1938.

The various methods by which the measurement of the primary and secondary currents in positive grid valves has been attempted are critically examined, and an original method is described for the accurate measurement of secondary-emission coefficients in valves. A study, by this method, of the secondary emission of variously prepared caesium-oxide surfaces is described.

THE ACCURACY OF RECTIFIER-PHOTOELECTRIC CELLS.*

By J. R. Atkinson, N. R. Campbell, E. H. Palmer and G. T. Winch (G.E.C. Research Laboratories).

Proc. Phys. Soc. 50, 934, November, 1938.

The effect of a resistance, R, in series with the cell on (*a*) the linearity of the response and (*b*) the temperature coefficient of the sensitivity is investigated. In order that no restriction shall be imposed on R by the effective sensitivity, the photoelectric current was measured by compensation. The light sources used in these experiments are tungsten filament vacuum lamps operating at a colour temperature of approximately 2400°K.

SURFACE MIGRATION OF BARIUM.*

By M. Benjamin and R. O. Jenkins (The M.O. Valve Co. and the G.E.C. Research Laboratories).

Phil. Mag. 26, 1049, December, 1938.

It is found under similar vacuum conditions that barium does not migrate over tungsten, although thorium does. It is also shown that barium does not migrate over nickel.

FIELD DISTRIBUTION AND GRAPHICAL RAY TRACING IN ELECTRON OPTICAL SYSTEMS.*

By L. Jacob (G.E.C. Research Laboratories).

Phil. Mag. 26, 570, October, 1938.

The electrolytic trough method is applied to an electron optical lens system for mapping out its field distribution to an accuracy of 2—3 per cent. The approximate electron trajectory for an electron entering the field in a direction parallel to the axis is calculated using the axial potential distribution and its derivatives.

ON THE EQUATION TO THE AXIAL POTENTIAL DISTRIBUTION IN ELECTRON OPTICAL SYSTEMS.*

By L. Jacob (G.E.C. Research Laboratories).

Phil. Mag. 26, 601, October, 1938.

The equation to the axial potential distribution of an electron optical system is derived from an accurate plot of the distribution to an accuracy of 1 per cent with the help of Legendre polynomials and the application of Simpson's rule. The calculation of electron trajectories through the field involves accurate values for the higher derivatives which can then be obtained by use of the equation.

THE RATIO OF PRIMARY TO SECONDARY LIGHT EMITTED IN FLUORESCENT DISCHARGE TUBES CONTAINING NEON.*

By H. G. Jenkins and J. N. Bowtell (G.E.C. Research Laboratories).

Trans. Faraday Soc. 35, p. 154, January, 1939.

In order to study further the fluorescent process, careful measurements have been made of the variations of the ratio of the fluorescent light to neon light with pressure, current density and tube diameter.

REFRACTORY MATERIALS.

By J. H. Partridge (G.E.C. Research Laboratories).

J. Royal Soc. Arts (Cantor Lectures), Vol. 87, pp. 227, 254, 283, January 13th, 20th, 27th, 1939.

The classification of refractory materials and the atomic structure of pure clays are discussed. Commercial materials consist of crystals set in a glassy matrix and it is shown that the latter is often the cause of failure. Methods of manufacture in which the glassy matrix is either controlled or eliminated are described. Such refractories are superior to those made by the methods in general use to-day.

* A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.

APPLICATIONS OF THE THERMIONIC VALVE TO PURPOSES OTHER THAN RADIO.

By H. J. N. Riddle (Siemens & General Electric Railway Signal Co., Ltd.).
Jnr. Inst. of Engineers, December 2nd, 1938.

Theory of the thermionic valve together with a description of a selected few typical uses, *e.g.*, the valve voltmeter, control of spot welding current, voltage stabiliser-rectifiers, etc.

SIGNALLING AT WAVERLEY STATION, EDINBURGH, L.N.E.R.

By F. Horler (Siemens and General Electric Railway Signal Co., Ltd.).
G.E.C. Journal, Vol. IX, No. 4, November, 1938.

General description with illustrations of a modern power signalling installation.

TRAIN DESCRIBERS.

By J. E. Mott (Siemens & General Electric Railway Signal Co., Ltd.).
Inst. Rlwy. Signal Engineers, November 16th, 1938.

Deals with impulse storage systems for train description between signal cabins. Characteristics of equipment employed. Automatic working. Design of systems and typical circuits.

OPTICAL SYSTEMS FOR LIGHT SIGNALS.

By J. E. Candler (Siemens and General Electric Railway Signal Co., Ltd.).
Inst. Rlwy. Signal Engineers, January 25th, 1939.

Lens systems for railway and road signals, effects on the human eye, colour measurement, suitable lamps, etc.

INSTRUMENTS INCORPORATING THERMIONIC VALVES, AND THEIR CHARACTERISTICS.

By E. G. James, G. W. Warren (G.E.C. Research Laboratories), and G. R. Polgreen (Salford Electrical Instruments, Ltd.).

Read before the I.E.E., but not yet published in the Journal of the Institution. Part I published in this issue of the G.E.C. Journal.

HIGH PRESSURE ELECTRIC DISCHARGE LAMPS AND THEIR APPLICATION.

By S. Anderson (G.E.C. Illuminating Engineering Dept.).
Penrose Annual, Vol. 41, December, 1938.

Characteristics of the Osira lamp and an explanation of its mode of working, with particular regard to its use in the printing trade. Application of the lamp to printing processes; its suitability for practically every type of work for which carbon arcs are normally employed.

MODERN ELECTRIC CLOCKS. PRINCIPLES, CONSTRUCTION, INSTALLATION AND MAINTENANCE.

By Stuart F. Philpott (Witton Engineering Works).
Pitman, 7/6.

An authoritative manual for clockmakers and electricians, fully illustrated with photographs and diagrams. It describes and illustrates every important principle of electric clock construction, installation and upkeep.

RECENT PROGRESS IN POWER RECTIFIERS AND THEIR APPLICATIONS.

By W. G. Thompson (G.E.C. Mercury Arc Rectifier Works, Witton).
Jour. I.E.E., Vol. 83, No. 502, October, 1938.

General survey of the present stage of development of power rectifiers. Water-cooled, pumpless air cooled, glass bulb and igniter types are considered and reference made to some of the leading non-vacuum types.

The scope and performance of rectifier installations are indicated with special reference to railway electrification, high voltage working and the applications of grid control.

THE DESIGN OF FRACTIONAL HORSEPOWER INDUCTION MOTORS.

By N. F. T. Saunders (Coldair, Ltd).
Jour. I.E.E., January, 1939.

The large amount of published material available to the designer of induction motors does not treat of fractional horsepower machines, especially for single-phase working.

Using analytical methods, the author establishes simple formulae for the performance data required in connection with single-phase motors, together with correction factors which yield accurate results. Similar correction factors, applicable to simple formulae commonly used in the design of polyphase motors, are also given. These correction factors are based on the conditions generally existing in fractional horsepower motors, which differ considerably from those found in large machines.

Recommendations regarding the active material required are included, also a method for determining slot ratios which are relatively free from cogging and noise.

Stator windings having a sinusoidal space distribution, and calculation of stator end-winding length and projection are also dealt with.

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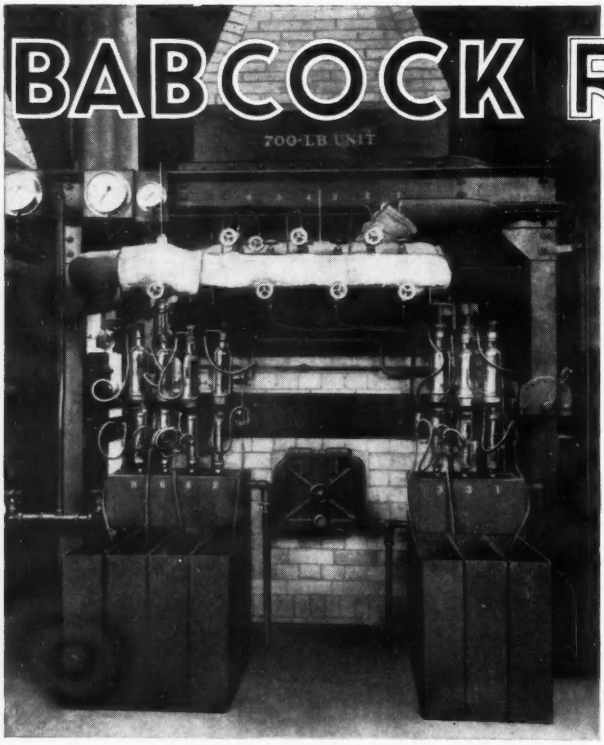
* A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.

BABCOCK RESEARCH



RESEARCH ADVERTISEMENT No. 4

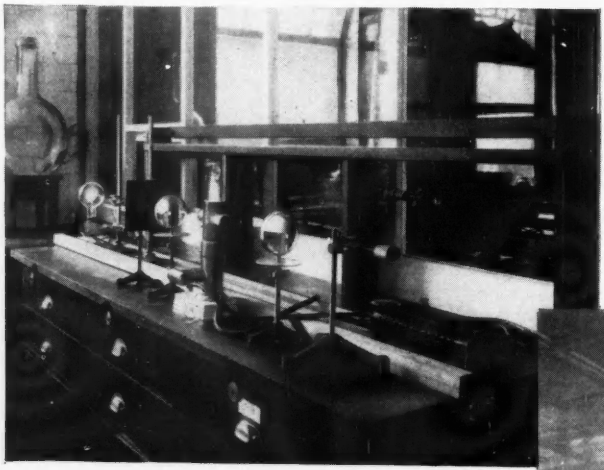
THE TESTING OF MATERIALS for use at high steam temperatures is an important factor in modern boiler construction. Research is necessary to ascertain the effect of high superheat temperature on the alloy steels now available.

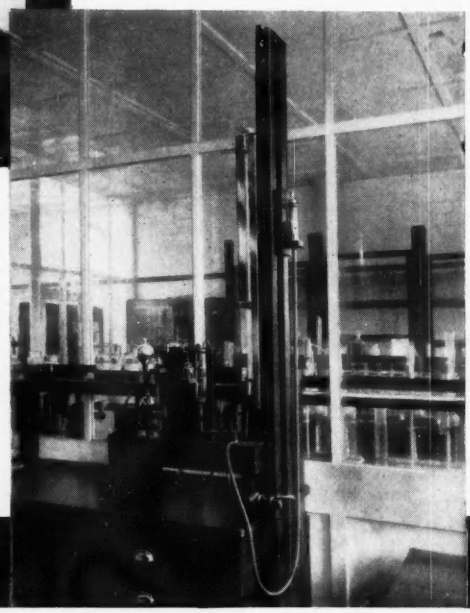
The development by Babcock & Wilcox Ltd., of special methods for the measurement of gas temperatures and for ascertaining the reaction between high temperature steam and tube metal has led to the recent introduction in their Laboratories of original apparatus for conducting tests of this kind.

The top illustration shows one of two special superheaters in which series of tubes of different materials are subjected to high steam temperatures to determine their resistance and behaviour under these conditions.

The operating conditions in these furnaces are closely controlled and special means are provided for recording the gas and tube wall temperatures.

The accurate determination of furnace gas temperatures where the conditions are not black-body is a difficult problem, necessitating the use of special apparatus. The centre illustration shows an adaptation of the Sodium Line Reversal Method which has been used for the determination of temperatures in internal combustion engines and is now, for the first time, being applied to boiler practice.





The lower illustration shows a Micro Gas Analysis Apparatus which enables analyses of very small quantities of gas to be carried out with speed and accuracy. The special apparatus used for the measurement of the rate of evolution of gas from condensed steam and for collecting gas samples is shown in front of the superheater in the illustration. This investigation is yet another example of the importance Babcock & Wilcox Ltd., attach to the results obtainable from practical research work.

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